LAKE UNION/SHIP CANAL/SHILSHOLE BAY

WATER QUALITY MANAGEMENT PROGRAM

DATA SUMMARY REPORT ADDENDUM

City of Seattle
Office for Long-range Planning
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EXECUTIVE SUMMARY

Introduction

This report summarizes new information (obtained since spring 1986) on water quality, sediment quality, crayfish contamination and benthic (bottom-dwelling) infauna in selected areas of Lake Union. Water quality parameters were compared with existing water quality standards and criteria. In the absence of freshwater sediment quality criteria, toxicant levels in Lake Union sediments were compared with interim sediment quality values proposed for Puget Sound sediments. Updates are also presented for five projects that are related to the overall Lake Union and Ship Canal Water Quality Management Program: (1) Seattle Engineering Department's Storm Drain Sediment Sampling and Analysis Study, (2) the related outfall survey conducted by the Environmental Intern Program, (3) Seattle Engineering Department's Combined Sewer Overflow Abatement Planning, (4) Metro's University Regulator CSO Control Project, and (5) Seattle Parks Department and U.S. Geological Survey's Gas Works Park Groundwater Analysis Program.

Water Quality

Metro's semimonthly monitoring of the Lake Union water column during July-December 1986 showed high conductivity in the Lake bottom during the summer and early fall, which reflects saltwater intrusion from the Locks. Dissolved oxygen levels were correspondingly low in the Lake bottom at that time, i.e., below the 5 mg/liter water quality criterion for protection of aquatic life. Fecal coliform counts exceeded the state water quality standard (> 50 organisms/ml water) during rainy periods in September-December.

Offshore Gas Works Park Sediment Quality

The triad approach (sediment chemistry analysis, sediment toxicity analysis and benthic infauna surveys) was applied to compare sediments from an offshore Gas Works Park (GWP) site in Lake Union and a reference site in pristine Chester Morse Lake (CML) (Yake et al., 1986). Offshore GWP sediment was contaminated with high levels of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs); no PAHs or PCBs were detected in CML sediment. Six metals (cadmium, chromium, lead, mercury, nickel and zinc) were found at higher concentrations in GWP than in CML sediments. GWP sediment was significantly more toxic to the freshwater amphipod *Hyalella azteca* than CML sediment, i.e., 95% *Hyalella* mortality compared to 8% mortality. The abundance and diversity of benthic infauna in GWP sediment were significantly lower than in CML sediment.

South Lake Union Pilot Project Addendum

As part of the South Lake Union Pilot Project, sediments were collected from fifteen sites in south Lake Union in spring 1986 and were analyzed for several sediment quality parameters including chemical oxygen demand (COD). Five of these sampling sites had sediment COD levels that were near or above 50 ppt, a concentration that has been associated with dissolved oxygen depletion and paucity of benthic infauna in Great Lakes sediments. It is likely that DO levels were low in these South Lake Union sediments, creating inhospitable conditions for benthic infauna.

Metal and PCB levels were measured in raw and cooked tail tissue of crayfish harvested from south Lake Union. The metal levels were within the range expected for crustaceans from urban waters and were not of concern to the Seattle-King County Health Department. The reported PCB levels were below the Food and Drug Administration tolerance standard of 2 ppm. However, this may be too liberal since it does not reflect the risk associated with consuming fish on a regular basis. The Seattle-King County Health Department has recommended further PCB analyses with replicate samples at each location and establishment of comparability between uncooked and cooked tissue.

In November 1986, the EPA Dive Team conducted a visual inventory of the bottom of Lake Union and collected sediment samples for benthic infauna and sediment grain size analyses from fifteen sites in south Lake Union and three additional sites on an east-west transect across the Lake. There was considerable variation among the 18 sampling sites with respect to depth, sediment conditions, consistency and percentage gravel, sand, silt and clay in the sediments. Benthic infauna were low in both abundance and diversity. Oligochaetes were found in 80% of the samples. Chironomid larvae were found in 50% of the samples. Clams, snails and copepods were found in either one or two samples. Four sites were completely devoid of animal life. Metal and organics analyses at five of the 18 sampling sites showed comparatively high levels of at least some toxic chemicals at each site, i.e., levels exceeding EPA's proposed interim benthic apparent effects threshold (AET) values for Puget Sound sediments. Quality assurance/quality control (QA/QC) data are being reviewed at present. Factors that may contribute to the observed paucity of benthic infauna are high toxicant levels in the sediments, saltwater intrusion, the accompanying low DO levels in the interstitial water in the sediments, and the high percentage of fine grains in many sediment samples.

Lake Union and Ship Canal Storm Drain Sediment and Analysis Program (Seattle Engineering Department)

The purpose of this study was to evaluate the pollutant input to Lake Union/Ship Canal caused by stormwater runoff from the surrounding urban watershed. Sediment samples were collected from eleven Lake Union/Ship Canal storm drainage basins. Stormwater samples were collected from four of these basins. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc and silver were found in all sediment samples. Sulfides were detected in only two sediment samples. Oil and grease, total organic carbon (TOC), and biological oxygen demand (BOD) concentrations exceeded concentrations measured in bottom sediments of Lake Union and the Ship Canal. The same was true for most of the metals especially lead, nickel, cadmium, copper and zinc.

Stormwater analyses showed that pollutant loading from first flush storms exceeds that from typical winter storms. Stormwater entering Lake Union/Ship Canal is generally less contaminated than stormwater in other cities with populations similar to Seattle. Basin 1 (Seaview) exhibited generally lower concentrations of pollutants in stormwater than Basins 5, 6 and 9. Based on comparisons of Lake Union/Ship Canal stormwater metal levels with acute water quality criteria, it appears that lead and copper are the contaminants of concern for long-term degradation of lake quality and impact on aquatic biota.

Mass loadings of stormwater pollutants to Lake Union and the Ship Canal were estimated, including total loadings from all storm drain outfalls for both the 10-year storm and average annual discharges and annual pollutant loadings from the four basins where stormwater was collected. Basin 6 is estimated to discharge the highest loading per acre of heavy metals, Basin 9 the highest loading per acre of total dissolved solids.

The storm drain basins were ranked based on their relative contributions of stormwater flow and pollutant loadings to Lake Union/Ship Canal. It appears that efforts to control stormwater volumes and pollutant loading would be most effective in the larger basins and in the medium-sized basins which exhibited the highest pollutant concentrations.

A followup source evaluation is currently underway to determine from which industrial or other shoreline uses the storm drain contaminants have come. Potential source control measures have been proposed.

Lake Union and Ship Canal Outfall Survey (Environmental Intern Program (EIP) and Seattle Engineering Department)

In summer-fall 1986, EIP volunteers identified 150 outfalls that discharge into Lake Union and the Ship Canal, classified these outfalls as storm drains, sewer drains, seeps or "other, unidentified", and identified owners/occupants of land near the outfalls.

Combined Sewer Overflow Abatement Planning (Seattle Engineering Department)

By January 1, 1988, the City of Seattle will have prepared a plan for "greatest reasonable reduction" of combined sewer overflow discharges in accordance with the requirements of a bill passed by the state legislature in 1985. The plan will focus on Lake Union, the Ship Canal, Elliott Bay and the Duwamish Waterway. Criteria are currently being developed to rank alternatives (e.g., complete separation, partial separation, storage) and to establish priorities for their implementation.

University Regulator CSO Control Project (Metro)

In order to assess potential impacts of alternatives for diverting stormwater from the Greenlake/I-5 University Regulator CSO, Metro collected baseline data on water quality, sediment quality and benthic infauna in Portage Bay, north Lake Union and the Ship Canal (at the Fremont Bridge). All six Portage Bay/Lake Union/Ship Canal water sampling sites were low in algae abundance and exhibited moderate to good water clarity. Washington State fecal coliform criteria were exceeded on at least some sampling dates at all sites. There was an increase in fecal coliform counts in a westward direction. Silver levels in the water column exceeded acute toxicity criteria on one sampling date at the University Regulator CSO sampling site, and exceeded chronic toxicity criteria on all sampling dates at all sampling sites. Zinc levels also exceeded chronic toxicity water quality criteria at the Lake Union/Gas Works Park site on two out of the eleven sampling dates. Nickel levels exceeded human health criteria at the I-5 bridge site on one sampling date. Arsenic levels exceeded these criteria at all sampling sites and on all sampling dates.

Sediments were sampled for conventional sediment quality parameters, metals and trace organics at eight sites. The University Regulator CSO site ranked lower in concentration than most other sites for most parameters. The I-5 bridge site had consistently higher concentrations for most parameters. The mid-Lake Union site had generally the highest concentrations for most metals; interim benthic AET values for Puget Sound sediments were exceeded here for silver, chromium, copper, nickel, lead and zinc. All Portage Bay sampling sites had lower concentrations of trace organics than Lake Union and downstream Ship Canal sampling sites. Twelve out of sixteen PAHs were found at the Ship Canal/Fremont Bridge site at levels exceeding benthic AETs for Puget Sound sediments. By contrast, no PAHs were found at levels exceeding benthic AETs at any of the Portage Bay sampling sites.

The University Regulator CSO site and the South Portage Bay site had the highest abundance of benthic infauna; the mid-Lake and Ship Canal/Fremont Bridge sites had the lowest abundance. More taxonomic groups were found in Portage Bay sediments than in Lake Union or Ship Canal sediments.

<u>Gas Works Park Groundwater Analysis Program</u> (Seattle Parks Department and U.S. Geological Survey)

This program was designed to determine if groundwater under and around Gas Works Park is contaminated with toxic chemicals and is migrating into Lake Union. Work performed thus far is: 1) seismic refraction survey to determine where to drill test wells; 2) drilling 16 test wells and 3) collection of groundwater samples. Results of the groundwater analyses (water temperature, pH, dissolved oxygen, conductivity, toxic chemicals) will be available in spring 1987.

I. INTRODUCTION

The Lake Union and Ship Canal Water Quality Management Program Data Summary Report presented available data (as of June, 1986) on water quality, sediment quality and biota in Lake Union and the Ship Canal, and discussed data gaps. In December 1986, the City released the final draft of the South Lake Union Pilot Project Report which compiled and analyzed 1986 data on water quality and sediment quality in south Lake Union, and implications for a proposed City park at the south end of the Lake.

In continuation of the South Lake Union Pilot Project, the City's Office for Long-range Planning (OLP) has conducted studies on crayfish contamination and benthic infauna (animals that live in the bottom sediments) in south Lake Union. OLP has also reviewed Lake Union water quality data from the second half of 1986 and synoptic data on Gas Works Park sediment quality, from a recently conducted study by the Washington Department of Ecology. Information from these new studies is presented in this Data Summary Report Addendum. As was the case for the original Data Summary Report, water quality data was compared with existing federal and state water quality standards and criteria. In the absence of freshwater sediment quality criteria, toxicant levels in Lake Union sediments were compared with interim sediment quality values proposed for Puget Sound sediments, i.e., benthic apparent effects threshold (AET) values.

This Data Summary Report Addendum also presents updates for five projects that are related to the overall Lake Union and Ship Canal Water Quality Management Program: (1) Seattle Engineering Department's Storm Drain Sediment and Analysis Program, (2) the related outfall survey conducted by the Environmental Intern Program, (3) Seattle Engineering Department's Combined Sewer Overflow Abatement Planning, (4) Metro's University Regulator CSO Control Project, and (5) Seattle Parks Department and U.S. Geological Survey's Gas Works Park Groundwater Analysis Program. Raw data from these ongoing studies is documented where available. Although there are still many gaps in what is known about environmental conditions in Lake Union and the Ship Canal, the new data presented in this report will be useful in prioritizing problem areas for source control and remedial actions.

II. ONGOING WATER QUALITY MONITORING

Metro continues to monitor the Lake Union water column on a semimonthly basis for conventional water quality parameters (see Figure 1 for location of Metro sampling site on the west side of the Lake). Major findings during July-December 1986 (Freshwater Assessment Reports, 1986) are summarized below for three of these water quality parameters that indicate water quality problems in the Lake (Table 1).

Saltwater Intrusion

Saltwater intrusion from Shilshole Bay into the Ship Canal and Lake Union, resulting from heavy usage of the Chittenden Locks during the summer months, is reflected in high conductivity and high turbidity in the Lake bottom from July-October. Conductivity in the Lake bottom returned to low values in November and December. This change reflects decreased saltwater intrusion and the mixing of the water column that occurs when Lake Union overturns in the fall.

TABLE 1 Cont.

DISSOLVED OXYGEN, CONDUCTIVITY, TURBIDITY AND FECAL COLIFORMS IN LAKE UNION

July - December 1986

DATE	DEPTH METERS	DO mg/l	COND., µmh/cm	TURB., NTU	FEC. COL., Organisms/100ml
12/02/86	1.0	10.1	102	0.7	61**
	5.0	9.9	102	0.8	
	10.0	9.9	101	0.8	
	14.0	9.9	100	0.7	
12/16/86	1.0	9.8	100	0.7	87**
	5.0	9.0	100	0.7	
	10.0	10.3	100	0.7	
	14.0	9.8	100	0.7	

* DO Levels do not meet water quality criteria for protection of aquatic life.

**Fecal coliform levels do not meet water quality criteria for protection of human health.

umh/cm = micromohs/centimeter
NTU = nephelometric turbidity units
Source: Freshwater Assessment Reports. 1986.

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TABLE 1

DISSOLVED OXYGEN, CONDUCTIVITY, TURBIDITY AND FECAL COLIFORMS IN LAKE UNION

July - December 1986

DATE	DEPTH (meters)	DO (mg/l)	COND., (µmh/cm)	TURBIDITY (NTU)	FECAL COLIFORMS (organisms/100ml)
7/08/86	1.0	9.7	140	0.7	31
	5.0	9.3	155	0.9	
	10.0	7.2	300	0.8	
	14.0	1.1*	2000	9.5	
7/22/86	1.0	9.1	151	2.1	17
	5.0	8.9	155	1.4	
	10.0	6.5	198	1.1	
	14.0	0.8*	750*	3.5	
8/05/86	1.0	9.6	141	0.6	39
	5.0	10.1	143	0.8	
	10.0	8.0	201	0.8	
	14.0	1.2*	915	5.4	
8/19/86	1.0	8.6	131	0.7	12
	5.0	9.4	132	0.7	
	10.0	4.7*	230	0.7	
	14.0	1.2*	840	5.2	
9/08/86	1.0	8.7	150	0.8	60**
	5.0	7.7	154	1.2	
	10.0	4.7*	310	0.8	
	14.0	1.7*	900	3.5	
9/23/86	1.0	7.9	250	1.2	91**
	5.0	5.5	250	1.3	
	10.0	3.9*	255	1.1	
	14.0	2.9*	1040	4.2	
10/07/86	1.0	8.0	230	0.7	23
	5.0	6.1	220	0.7	
	10.0	5.7	240	0.7	
	14.0	4.4*	290	1.2	
10/21/86	1.0	8.7	210	0.7	73**
	5.0	10.5	205	0.8	
	10.0	9.6	210	0.7	
	14.0	4.9*	800	1.2	
11/03/86	1.0	8.7	180	0.9	44
	5.0	8.4	185	1.1	
	10.0	8.6	175	0.9	
	14.0	7.9	171	0.8	
11/19/86	1.0	9.3	126	0.9	98**
	5.0	7.5	125	0.9	
	10.0	7.5	126	1.0	
	14.0	7.8	126	0.9	

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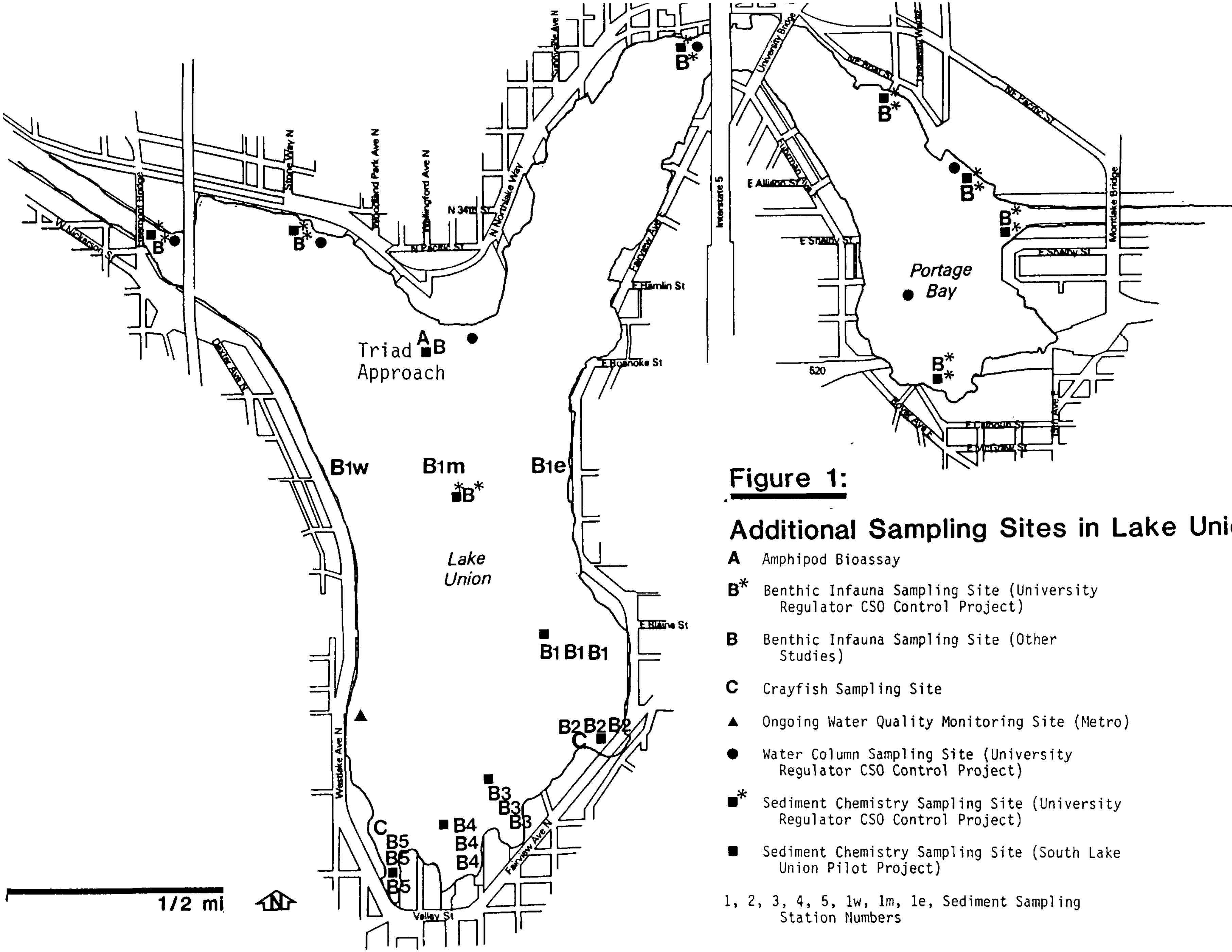

Figure 1:

Additional Sampling Sites in Lake Union

A Amphipod Bioassay

B* Benthic Infauna Sampling Site (University Regulator CSO Control Project)

B Benthic Infauna Sampling Site (Other Studies)

C Crayfish Sampling Site

▲ Ongoing Water Quality Monitoring Site (Metro)

● Water Column Sampling Site (University Regulator CSO Control Project)

■* Sediment Chemistry Sampling Site (University Regulator CSO Control Project)

■ Sediment Chemistry Sampling Site (South Lake Union Pilot Project)

1, 2, 3, 4, 5, 1w, 1m, 1e, Sediment Sampling Station Numbers

Water Column

Dissolved oxygen (DO) levels were correspondingly low in the Lake bottom from July - October, i.e. below the 5 mg/l water quality criterion for protection of aquatic life. In November and December, when the Lake bottom was less saline and water temperatures were lower, DO levels met the water quality criterion throughout the water column.

Fecal Coliforms

Fecal coliform counts met state water quality standards (≤50 organisms/ml) during July and August. This means that the counts were not high enough to threaten the health of people engaged in water contact sports. Fecal coliform counts did exceed the water quality standard during rainy periods in September-December.

III. OFFSHORE GAS WORKS PARK SEDIMENT QUALITY

The triad approach (sediment chemistry analysis, sediment toxicity analysis and benthic infauna surveys) was applied to compare sediments from an offshore Gas Works Park (GWP) site in Lake Union (Figure 1) and a reference site in pristine Chester Morse Lake (Yake et al., 1986). Chester Morse Lake (CML) was chosen as a reference site because it is located within the protected watershed of the Seattle Water Department. Human activities that could contribute contamination to the waters and sediments of Chester Morse Lake are therefore minimized.

Sediment Chemistry

Table 2 compares levels of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in offshore GWP and in CML sediments. Offshore GWP sediment was contaminated with high levels of PAHs (ranging from 40 ppm for naphthalene and fluorene to 750 ppm for pyrene) and PCBs (4.3 ppm). These PAH and PCB levels exceeded the Environmental Protection Agency's proposed interim benthic apparent effects threshold (AET) values for Puget Sound sediments. By contrast, no PAHs or PCBs were detected in CML sediment.

Table 3 compares levels of metals in offshore GWP and in CML sediments. The following six metals were found at higher concentrations at the GWP site: cadmium (4X as high), chromium (2X as high), lead (22X as high), mercury (9X as high), nickel (9X as high) and zinc (4X as high). Lead, nickel and zinc levels in the GWP sediment sample exceeded interim benthic AET values for Puget Sound sediments.

Sediment Toxicity

Sediment toxicity was determined by a bioassay, using the freshwater amphipod *Hyalella azteca*. This amphipod was exposed to various concentrations of GWP and CML sediments for ten days. GWP sediment was significantly more toxic to *Hyalella* than CML sediment, with toxicity generally increasing as the GWP content of the sediment increased (Table 4). *Hyalella* mortality was 95 percent when exposed to undiluted GWP sediment compared to 8 percent when exposed to undiluted CML sediment.

TABLE 2

ORGANIC LEVELS IN LAKE UNION
(OFFSHORE GAS WORKS PARK)
AND CHESTER MORSE LAKE SEDIMENTS

Organic Chemical	Gas Works Park (ppm dry weight)	Chester Morse Lake (ppm dry weight)
Polycyclic Aromatic Hydrocarbons		
Naphthalene	40J	100u
Acenaphthylene	92	100u
Fluorene	40J	100u
Phenanthrene	410	100u
Anthracene	120	100u
Fluoranthene	570	100u
Pyrene	750	100u
Benzo(a)anthracene	170	100u
Chrysene	170	100u
Benzo(k)fluoranthene	240	100u
Benzo(a)pyrene	220	100u
Indeno(1,2,3-cd)pyrene	120	100u
Benzo(g,h,i)perylene	190	100u
Benzo(a)pyrene	280	100u
Pesticides/PCBs		
PCB-1242	4.3	60u

u = Not detected at detection limit specified
J = Estimated value.

Source: Yake et al. 1986

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TABLE 3

METAL LEVELS IN LAKE UNION
(OFFSHORE GAS WORKS PARK)
AND CHESTER MORSE LAKE SEDIMENTS

Metals	Gas Works Park (ppm dry weight)	Chester Morse Lake (ppm dry weight)
Cadmium	1.98	0.46
Chromium	20	10
Copper	156	160
Lead	300	13.9
Mercury	0.173	0.019
Nickel	88.3	9.8
Zinc	320	84

Source: Yake et al. 1986

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TABLE 4

RESULTS OF AMPHIPOD (*Hyalella azeteca*)
SEDIMENT BIOASSAY IN LAKE UNION
(OFFSHORE GAS WORKS PARK)
AND CHESTER MORSE LAKE SEDIMENTS

Percent* Gas Works Park Sediment	Percent Chester Morse Lake Sediment	Average Mortality (percent, 3 replicates)
0	100	8.3
1	99	6.7
3.3	96.7	13.3
10	90	13.3
33	67	20
100	0	95

*Percent determined on a weight basis.

Source: Yake et al. 1986.

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Benthic Infauna

Table 5 compares numbers of animals found in major taxonomic groups in both GWP and CML sediments and compares diversity of taxonomic groups, as indicated by Brillouin's Diversity Index and the Shannon-Weaver Diversity Index. The abundance and diversity of benthic infauna in offshore GWP sediment were significantly lower than in CML sediment. Diversity was almost twice as high in sediment from the reference site as in sediment from the offshore GWP site.

IV. SOUTH LAKE UNION PILOT PROJECT ADDENDUM

Interpretation of Sediment Chemical Oxygen Demand Values

As part of OLP's South Lake Union Pilot Project, sediments were collected from five areas in south Lake Union in spring 1986 (see Figure 1 for location of areas), at distances of 50', 150' and 300' from the shoreline within each area. In this report, the sampling sites will be referred to as 1-50, 1-150, 1-300 (also called 1-Drydock), 2-50, 2-150, 2-300, etc. Sediments from the fifteen sites were analyzed for several sediment quality parameters including chemical oxygen demand (COD). This parameter is a measure of the amount of oxygen in a sediment sample that is consumed by the chemicals present in that sample. COD levels in the tested Lake Union sediments ranged from 2 parts per thousand (ppt) at site 4-50 to 71 parts per thousand (ppt) at site 4-300 (South Lake Union Pilot Project Report, 1986).

High COD levels are usually correlated with low DO levels. Field investigations of GOD values in Lake Michigan sediments have provided a yardstick for judging how high is high. Gardiner et al. (1985) found that regions of Green Bay (a large gulf in the northwest corner of Lake Michigan) with sediment COD > 50 mg O_2/gram dry weight (>50 ppt) exhibited DO depletion and were poorly colonized by benthic infauna. Auer and Auer (1986) found that regions of Fox River (Green Bay's major tributary) with sediment COD > 50 ppt exhibited DO depletion and had levels of hydrogen sulfide and ammonia-nitrogen that are potentially toxic to aquatic life.

Two sampling sites in south Lake Union had sediment COD levels that exceeded 50 ppt (68 ppt at 3-300 and 71 ppt at 4-300). Three other sampling sites had sediment COD levels of 50 ppt (5-150) or close to 50 ppt (48 ppt at 1-150 and 5-50). It is likely that DO levels were low in these sediments, creating inhospitable conditions for benthic infauna. For more information on this subject, see the discussion in this report on the benthic infauna survey conducted in the vicinity of the South Lake Union pilot project sampling sites.

Crayfish Tissue Analyses

Metal and PCB levels were measured in raw and cooked edible (tail) tissue of crayfish harvested in summer - fall 1986 from south Lake Union near the City Light Steam Plant (30 crayfish) and near the proposed new City park (22 crayfish) (see Figure 1 for harvest locations). The crayfish were frozen and divided into two groups: one for metal analyses and one for PCB analyses. Thawing took place on the day that the analyses were performed.

TABLE 5

BENTHIC INFAUNA[1] IN LAKE UNION
(OFFSHORE GAS WORKS PARK)
AND CHESTER MORSE LAKE SEDIMENTS

Taxonomic Groups	Lake Union	Chester Morse Lake
Unsegmented worms	3	0
Nematodes	3	31
Oligochaetes	208	184
Other segmented worms	0	15
Snails	0	7
Clams	18	41
Hydra	1	0
Bryozoa	1	0
Amphipods	0	24
Other Arthropods	1	5
Chironomids	7	372
Other insects	0	2
Brillouin's Diversity Index	1.69	2.95
Shannon-Weaver Diversity Index	1.79	3.04

[1]Each number is the total for four replicate sampling sites and represents the number of animals found per 0.0232 m^2 grab.

Source: Yake et al. 1986.

(209)792.T5

For measuring metal levels, the tails were removed from each crayfish. The tail samples from half of the crayfish were boiled in distilled, deionized water in a Pyrex glass container until the shells turned red in color; tail meat was dissected from the shells in both cooked and uncooked samples. The cooked meat was treated as one composite sample; the uncooked meat was treated as another composite sample. Each composite sample (10 grams of tail meat) was digested with concentrated nitric acid and hydrogen peroxide and analyzed for nine heavy metals in accordance with EPA Method 600/4-79-020. Arsenic, chromium and silver levels were determined by graphite furnace atomic absorption; all matrix interferences were determined and corrected. Mercury levels were determined by cold vapor; cadmium, copper, lead, nickel and zinc levels were determined by flame atomic absorption. An extraction blank was analyzed with every heavy metal determination for quality assurance/quality control. Analyses of blanks demostrated that there was no contamination from the laboratory procedures above the minimum detection limits.

For measuring PCB levels, half of the total number of crayfish were boiled whole for 5 minutes in tap water in a Pyrex glass container. Tail meat was dissected from both cooked and uncooked fish. The cooked meat was treated as one composite sample; the uncooked meat was treated as another composite sample. Each composite sample (20-30 grams of tail meat) was analyzed for PCBs by gas chromatography in accordance with EPA Method 8080. Two extraction blanks and one spike were run for quality assurance/quality control. Analyses of blanks demonstrated that there was no contamination from the laboratory procedures above the minimum detection limits. The spike recovery rate of 115 percent also indicated no significant contamination from the laboratory procedures.

Metals. Table 6 presents heavy metal levels found in raw and cooked tail meat of crayfish harvested from south Lake Union, and compares this data with data obtained for crayfish harvested from three other sites: 1) Lake Union off Gas Works Park, 2) the Montlake Cut and 3) the Ship Canal (Frost et al., 1984). Metal levels in raw and cooked crayfish tail tissue were within the range expected for crustaceans from urban waters and were not of concern to the Seattle-King County Health Department. The U.S. Food and Drug Administration (FDA) has established tolerance standards for mercury (0.5 ppm) and cadmium (1 ppm) in shellfish and fish. Mercury levels (<0.1 ppm) and cadmium levels (0.08 - 0.39 ppm) in both raw and cooked tail tissue of crayfish harvested from south Lake Union did not exceed the tolerance standards. With the exception of arsenic, all metal levels are consistent with previous studies conducted on Lake Union crayfish and other crustacean and clam samples collected around Puget Sound. Arsenic levels (1.9-5.1 ppm raw, 3.8-9.9 ppm cooked) were higher than in crayfish harvested in 1984 (Frost et al., 1984) from offshore Gas Works Park, the Montlake Cut and the Ship Canal, but were still within the range reported in shellfish from other studies (e.g., comparable levels found in littleneck clams harvested at the ferry dock at Tahlequah on Vashon Island) (Price, 1978). Furthermore, most of the arsenic absorbed by seafood is in protein-bound, non-toxic forms which are readily excreted, unchanged, by humans.

METAL AND PCB LEVELS IN CRAYFISH TAIL TISSUE (ppm wet weight)

Metal/PCBs	Station 2		Station 5		Montlake Cut*	Gas Works Park*	Ship Canal*
	Raw	Cooked	Raw	Cooked	Cooked, 9/84	Cooked, 9/84	Cooked, 9/84
Arsenic	5.1	9.9	1.9	3.8	0.22	0.34	0.62
Cadmium	0.12	0.39	0.09	0.08	0.05	0.03	0.44/0.62
Chromium	<0.01	0.05	<0.01	0.05	NA	NA	NA
Copper	3.4	9.7	1.6	8.9	18.8	ND	20.6/25.4
Lead	0.06	1.1	0.51	1.0	1.5	0.41	0.83/0.75
Mercury 1/	<0.1	<0.1	<0.1	<0.1	0.24	0.21	0.18
Nickel	0.92	0.64	0.37	0.41	NA	NA	NA
Silver	0.15	0.35	0.25	0.30	NA	NA	NA
Zinc	10	21	8.6	17	NA	NA	NA
Total PCBs 2/	0.09	0.66	<0.04	0.06	0.01	0.17	0.11

* These values are from: Frost, et al. 1984. Duplicate values were obtained in a few cases. In the study by Frost et al., whole crayfish were cooked, and tail meat was dissected out.

ND = not detected.

NA = not applicable. This means that the particular metal was not analyzed in crayfish at that station.

1/ = Food and Drug Administration standard for mercury in fish and shellfish is 0.5 ppm and for cadmium in fish and shellfish is 1 ppm.

2/ = Food and Drug Administration standard for PCBs in fish and shellfish is 2 ppm.

(209)792.T6

PCBs. Table 6 presents PCB levels found in raw and cooked tail tissue of crayfish harvested from south Lake Union, and compares this data with data obtained for crayfish harvested from three other sites in Lake Union/Ship Canal. The reported PCB level of 0.66 ppm in cooked tail tissue of crayfish harvested near the City Light Steam Plant was 4-6 times as high as the PCB levels measured in crayfish harvested from offshore Gas Works Park and the Ship Canal in 1984.

This concentration is still well below the FDA tolerance standard for PCBs in shellfish and fish (2 ppm). However, FDA tolerance standards are aimed at regulating toxicants in shellfish and fish in interstate commerce for which a national market exists and for which it is appropriate to use national consumption figures. More conservative values may be needed to protect local populations consuming large quantitites of shellfish and fish from local waters. Therefore, the standard for PCBs may be too lenient for protecting the health of people who consume large quantities of crayfish from Lake Union.

The reported PCB level in cooked tail tissue of crayfish harvested near the City Light Steam Plant was 7 times as high as the reported PCB level (0.09 ppm) in raw tail tissue of crayfish harvested from the same area. The raw tissue weight of 30 grams compared to the cooked tissue weight of 20 grams suggests the evaporation of water during the cooking process may have concentrated PCBs in the cooked tissue. Migration of PCBs from the hepatopancreas to the muscle tissue during the cooking process is another plausible explanation. However, we lack data to determine if the two samples were equivalent in total fish weight, age distribution (older crayfish could pick up more PCBs from their environment than younger fish) and percent lipids in tail tissue (which would affect uptake of PCBs). The Seattle-King County Health Department has recommended further PCB analyses with replicate samples at each location and establishment of comparability between cooked and uncooked tissue.

Benthic Infauna Survey. The purpose of this survey was to obtain a general idea of what animals, if any, were living beneath the sediments in some areas of Lake Union. The survey was not intended to be a comprehensive assessment of the Lake Union benthic community.

In November 1986, the EPA Dive Team conducted a visual inventory of the bottom of Lake Union and collected sediment samples for benthic infauna and sediment grain size analyses from fifteen sites in the south end of the lake and three additional sites on an east-west transect across the lake (see Figure 1 for location of sampling sites). Diver-held cores (area of cylinder face = 21.36 cm^2, collection depth = 10 cm beneath surface) were used for sediment sampling at all sites except four (1-150, 1-Drydock, 2-50, 3-300) where the sediments were too soft to be contained in the cores and the mid-lake site (1-M) where diving was considered unsafe. Core subsamples of Van Veen grabs were taken at these five sites, using the diver-held cores and collecting 10 cm beneath the surface.

For each sampling site, sediment samples for benthic infauna analysis and for grain size analysis were placed in separate, labelled plastic bags which were stored outdoors (air temperature = 35°-40°F) until the end of the two day sampling period. Each sample consisted of the entire contents of one core rather than a composite of several cores. One set of samples was delivered to Laucks Testing Laboratories (Seattle, WA) for grain size analysis of the sediments using the pipet modification of ASTM Method D-422. The other set of samples was processed for benthic infauna analysis by Invert-Aid (Tacome, WA).

The samples were fixed in 7 percent buffered formalin and, after a minimum of two days fixation, were washed in tap water, screened through a 0.5 mm mesh and preserved in 70 percent ethanol. Samples were examined through a binocular microscope at 10x to 30x. Notes were made on sediment characteristics, and unusual odors and sheens detected during the washing process. Benthic infauna were removed from the sediments, identified by major taxonomic groups and counted. Residues were retained; residues and benthic infauna are archived at the Invert-Aid laboratories. In order to check the consistency of quality, six of the samples (30% of the samples) were resorted. No previously undetected specimens were found during this procedure.

In addition to collecting sediment samples for benthic infauna and sediment grain size analyses, the EPA Dive Team took Van Veen grabs at 1-Drydock, 2-50, 3-300, 4-300 and 5-50 for analyses of metal, PCB and PAH levels in the sediments. These sites were selected for sediment chemistry testing because they were the most heavily contaminated (1-Drydock, 2-50, 3-300, 5-50) at four sampling areas and the least contaminated at one sampling area (4-300) in the South Lake Union Pilot Project. The sediment samples were placed in clean glass jars for transportation to the EPA Laboratory (Manchester, WA) for sediment chemistry analyses. Recommended protocols of the Puget Sound Estuary Program were followed in collecting these samples (Tetra Tech, 1986b).

Results. There was considerable variation among the 18 sampling sites with respect to depth, sediment conditions, consistency and particle size (percentage gravel, sand, silt and clay in the sediments) (Tables 7-8). Sediments were fine-grained and soft in many places, oily in others, gelatinous in others. The EPA divers observed crayfish at two stations (1-50 and 4-150) and some plant life (Elodea, a filamentous green alga) at a few other stations (3-150, 3-300, 5-50, 1-E) but no other animal life was apparent during their visual inventory of the Lake bottom.

Table 9 presents the results of the benthic infauna survey. Two sets of numbers are given for each group: the actual number of specimens found in the sample, and an estimated number of individuals that would be found in one square meter (m^2) of sediment if the animals were uniformly distributed throughout the sediment (uniform distribution may or may not be the case). The latter numbers were obtained with a formula used in Metro benthic infauna surveys: $N = s \times 10^6/2136$ where s = the number of specimens in the sample and 2136 = the surface area of the sampler face in square millimeters (mm^2). For comparative purposes, benthic infauna analysis data from Gas Works Park offshore sediments and from Chester Morse Lake sediments (Yake et al, 1986) are also presented in Table 9. Numbers are not presented for two samples (5-150 and 5-300) because these samples were inadvertently misplaced for two weeks, hence precluding accurate analyses.

Benthic infauna were low in both abundance and diversity. Oligochaetes, a group of segmented worms which inhabit clean areas and also tolerate highly organic, low oxygen conditions, were found in 80% of the samples (3 to 300 animals per sample). Chironomid (midge) larvae, which can also tolerate anaerobic conditions, were found in 50% of the samples (1 to 3 animals per sample). Three clams were found in one sample, one snail was found in a different sample and four amphipods were found in yet another sample. Four sites (1-Drydock, 2-300, 4-300 and 1-M) were completely devoid of animal life. A paucity of benthic infauna means a paucity of food for resident fish.

TABLE 7

LAKE UNION SEDIMENT CONDITIONS

STATION	CONDITION [1/]	DEPTH[2/] (meters)	SAMPLE TYPES
1-50	very oily, detritus, black mud with white fungus	7.2	Cores
1-150	oily, bits of plastic, mud, wood debris	10.8	Van Veen
1-Drydock	fine detritus	12.8	Van Veen
2-50	grey clay with greenish tinge, thick layer with organic debris and gelatinous consistency	9.5	Van Veen
2-150	grey clay, no residue, thick layer with organic debris as in 2-50	11.1	Cores
2-300	clay, no residue, thick layer with organic debris as in 2-50	8.9	Cores
3-50	black sand, detritus	5.0	Cores
3-150	rock, gravel, lots of plant material (e.g. *Elodea*)	5.1	Cores
3-300	sand, gravel, plant detritus, *Elodea*	10.4	Van Veen
4-50	wood debris, sand, fine gravel	3.2	Cores
4-150	wood debris, sand, fine gravel	8.3	Cores
4-300*	blue clay, some gravel	6.6	Cores, Van Veen
5-50A*	wood debris, *Elodea*	6.5	Cores, Van Veen
5-50B	wood debris	6.5	Cores
5-50C	wood debris	6.5	Cores
5-150	wood debris, oily smell and sheen	6.0	Cores
5-300	wood debris, oily smell and sheen	8.1	Cores

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TABLE 7 (Cont.)

LAKE UNION SEDIMENT CONDITIONS

STATION	CONDITION	DEPTH (meters)	SAMPLE TYPES
1-W	grey clay, detritus (fibrous), small wood particles	N/A	Cores
1-M	some detritus, clay, small particles	N/A	Van Veen
1-E	oil, wood debris, Elodea, grey sediments with brown streaks	N/A	Cores

1/ Descriptions of sediment conditions are based on visual observation of sediments and photographs taken.

2/ For each sampling site, the sediment sample was collected at the same depth as in the South Lake Union Pilot Project.

N/A = data not available for this station.

* = At these stations, diver held cores were used to collect sediment for benthic infauna and grain size analyses. The Van Veen grab sampler was used to collect sediment for sediment chemistry analysis.

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TABLE 8

GRAIN SIZE ANALYSIS
OF LAKE UNION SEDIMENT SAMPLES

PERCENT SEDIMENTS (dry weight)

STATION	GRAVEL (> 2mm)	SAND (>62 um -<2mm)	SILT (>4 um -<62um)	CLAY (< 4um)	MISCELLANEOUS*
1-50	0.0	71.0	13.3	12.7	3.0
1-150	0.0	67.0	14.2	18.8	0.0
2-50	0.0	2.5	70.1	27.4	0.0
1-Drydock	0.0	53.7	29.8	16.5	0.0
2-150	0.0	2.2	73.6	24.2	0.0
2-300	0.0	1.9	67.3	30.8	0.0
3-50	0.0	69.2	26.8	0.0	4.0
3-150	23.0	59.5	15.1	2.4	0.0
3-300	18.0	64.8	14.3	2.9	0.0
4-50	20.0	78.3	1.5	0.2	0.0
4-150	0.0	49.8	38.6	9.6	2.0
4-300	54.0	43.6	1.1	1.3	0.0
5-50	0.0	47.9	45.4	6.7	0.0
5-150	0.0	53.3	40.6	6.1	0.0
5-300	18.0	58.9	17.5	5.6	0.0
1-W	0.0	8.1	54.7	37.2	0.0
1-M	0.0	13.8	37.2	49.0	0.0
1-E	0.0	30.0	42.2	23.8	4.0
Gas Works Park, offshore	5.1	45.9	36.9	12.1	0.0

* Organic matter retained on 2 mm sieve

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Two caveats must be considered in analyzing the benthic infauna data. Since there was scant prior information on benthic infauna in Lake Union and since the City's sampling funds were limited, EPA and other agencies recommended taking one sample at each site rather than three replicates at each site. Therefore, the benthic infauna found in each sample are not necessarily representative of the benthic infauna in the adjacent areas. At the one site (5-50) where three replicates were taken, diversity varied among the replicates. Sample 5-50A contained oligochaetes, chironomids and amphipods (the only amphipods found in this survey). This sample also contained Elodea with which the amphipods are probably associated. Sample 5-50B contained only oligochaetes. Sample 5-50C contained oligochaetes and chironomids.

A second caveat is that core subsamples taken from Van Veen grabs at five sites may not have been representative samples because the sampling process may disrupt the natural spatial distribution of motile animals. For example, surface-dwelling animals may move to the edges of the sample as the grab is being retrieved. The number and type of animals identified may have been different if it had been possible to collect sediment with diver-held cores at those sites.

Table 10 presents data on metal and organics levels in the five sediment samples where sediment chemistry testing was performed. The review of the quality assurance/quality control (QA/QC) data is forthcoming. As was the case in the South Lake Union Pilot Project, 1-Drydock was the site with the highest metal levels and 2-50 was the site with the highest PCB levels. Each site had comparatively high levels of at least some toxic chemicals, i.e., levels exceeding EPA's proposed interim benthic apparent effects threshold (AET) values for Puget Sound sediments. These values are sediment toxicant levels that, when present, are associated with a decrease in the number and types of benthic infauna in Puget Sound sediments (Tetra Tech, 1986a). Benthic AET values have not been proposed for freshwater sediments. The Puget Sound numbers may or may not be applicable to Lake Union benthic infauna; the numbers are used here for comparative purposes because they are the best yardsticks available at present.

Given these caveats, the sediment chemistry analyses showed that zinc levels were elevated in sediments from all five sites; nickel levels were high at all sites except 4-300, and lead levels were high at all sites except 3-300 and 4-300. Arsenic and cadmium levels were also particularly high at the 1-Drydock site. Total PCBs exceeded the benthic AET value for Puget Sound sediments at 2-50. Some PAHs were also found at levels exceeding benthic AETs for Puget Sound sediments at some of the sampling sites.

TABLE 9
LAKE UNION BENTHIC INFAUNA SAMPLING RESULTS

TATION	OLIGOCHAETA (worms)	CHIRONOMID LARVAE (insects)	PELECYPODA (clams)	GASTROPODA (snails)	AMPHIPODA (crustacea)	NEMA-TODES	OTHER
-50	51:23,876	2:936					
-150	70:32,771			1:468			
-Drydock	0:0						
-50	6:2,808	2:936	3:1404				
-150	3:1404	3:1404					
-300	0:0						
-50	142:66,479	1:468					
-150	300:140,449	3:1404					
-300	61:28,558	3:1404					
-50	58:27,153 16:7,490*	1:468					1:468
-150	6:2808						
-300	0:0						
-50A	14:6554	1:468			4:1872		
-50B	8:3745						
-50C	6:2808	3:1404					
-M	0:0						
-E	10:4681	1:468	2:936				
-W	4:1872						
as Works ark1/ ffshore	19:8,895	1:468	2:936				1:468
hester orse ake1/	17:7,956	34:15,912	4:1,872	1:468	2:936	3:1,404	2:936

umbers indicate individuals per sample: followed by estimated numbers/m^2.

Oligochaete cocoons (Barnes, 1980).

/These numbers are from Yake, et al. (1986). The sampling device used in their study had surface area of 232 cm^2. The original numbers obtained were therefore corrected for he surface area of the sampling device (21.36 cm^2) used in the benthic infauna study onducted by the Office for Long-range Planning, i. e., the numbers from Yake, et al 1986) are divided by 11.

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TABLE 10
METAL AND ORGANICS LEVELS IN
SOUTH LAKE UNION SEDIMENT SAMPLES

Chemical Level, ppm dry weight	Sample Site				
	1-Drydock	2-50	3-300	4-300	5-50
Arsenic (85)*	1470**	41	7.3	0.48	20.3
Cadmium (5.8)	5.12	3.86	1.7	1.76	4.09
Chromium (59)	108.5**	64.8**	38.8	29.2	42.5
Copper (310)	2177**	724**	99.2	195.7	232.3
Lead (300)	2394**	1025**	289	242	1216**
Nickel (49)	54.9**	83.8**	50**	34.9	50.9**
Silver (5.2)	3.55	4.39	0.46	1.70	1.85
Zinc (260)	6060**	880**	300**	670**	650**
Mercury (0.88)	2.3**	0.20	0.14	0.066	0.12
PCB-1260	0.29	0.36	0.062	ND	0.23
PCB-1254	0.61	1.20	0.18	0.21	0.50
PCB-1221	ND	ND	ND	ND	ND
PCB-1232	ND	ND	ND	ND	ND
PCB-1248	ND	ND	ND	ND	ND
PCB-1016	ND	ND	ND	ND	ND
PCB-1242	ND	ND	ND	ND	ND
TOTAL PCBs (1.10)	0.90	1.56**	0.242	0.21	0.73

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TABLE 10 Continued
METAL AND ORGANICS LEVELS IN
SOUTH LAKE UNION SEDIMENT SAMPLES

Chemical Level, ppm dry weight	Sample Site				
	1-Drydock	2-50	3-300	4-300	5-50
Benzo(a)pyrene (6.80)	1.2	3.7	1.1	2.3	2.1
Dibenzo(a,h)anthracene (1.20)	ND	2.3**	0.9	1.0	1.6**
Benzo(a)anthracene (4.50)	1.3	2.6	1.1	3.0	1.7
Acenaphthene (0.50)	ND	ND	ND	ND	ND
Phenanthrene (3.20)	1.8	4.5**	2.2	11	4.1**
Fluorene (6.40)	ND	ND	ND	ND	ND
Naphthalene (2.10)	ND	ND	ND	ND	ND
Anthracene (1.30)	0.4	1.1	0.3	1.6**	0.06
Pyrene (7.30)	0.3	1.3	0.6	0.5	1.0
Benzo(ghi)perylene(5.40)	2.2	6.2**	2.1	4.2	3.5
Indeno(1,2,3-cd)pyrene (8.00)	0.8	2.4	0.8	0.8	1.2
Benzo(b)fluoranthene (6.30)	1.7	4.9	1.5	3.0	2.9
Fluoranthene (6.30)	2.4	5.3	2.2	8.4**	3.7
Benzo(k)fluoranthene(0.64)	0.7	1.7	0.6	1.3	1.0
Acenaphthylene (0.64)	ND	ND	ND	ND	ND
Chrysene (6.70)	1.3	3.7	1.4	2.6	2.5

* The number in parentheses after the name of each chemical is the benthic apparent effects threshold (A.E.T.) value, in ppm, for Puget Sound sediments.

** These levels exceed benthic A.E.T. values for Puget Sound sediments.

ND = not detected

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High toxicant levels may be partly responsible for the observed paucity of benthic infauna. Other likely contributing factors are the saline content of the sediments due to saltwater intrusion from the Locks, the accompanying low DO levels in the interstitial water in the sediments, and the high percentage of fine grains in many sediment samples. In general, more animals were found in the shallowest sites (< 6 meters) where the sediments would be less saline and more oxygenated than in the deepest sites (> 10.5 meters). No animals were found in sediments at the two deepest sites (1-Drydock and 1-M). In addition, sediments at 1-Drydock were contaminated with high levels of several metals and contained 50 percent fine-grained particles (silt and clay). Sediments at 1-M contained 86% silt and clay. By contract, animals were comparatively numerous at 3-300 and diverse at 5-50. Both these sites were shallower and less contaminated than 1-Drydock; 3-300 contained a high percentage of sand and low percentages of fine grains. In order to perform an accurate analysis of factors responsible for low abundance and diversity of benthic infauna, it would be necessary to have synoptic data including sediment chemistry, benthic infauna (mean and standard deviation for three replicates), DO and salinity for each sampling site. Although synoptic data is lacking, the information that is available on sediment chemistry and benthic infauna indicates that the lake ecosystem is not healthy, at least in South Lake Union.

V. RELATED PROJECTS

Lake Union and Ship Canal Storm Drain Sediment and Analysis Program (Seattle Engineering Department).

The purpose of this study was to evaluate the pollutant input to Lake Union/Ship Canal caused by stormwater runoff from the surrounding urban watershed. To distinctly identify stormwater contributions to pollutant input, the separate storm drainage system was studied rather than the combined sanitary and stormwater system. The study scope and results are summarized below from Kennedy/Jenks/Chilton (1987).

Sediments were collected from eleven of the twenty major Lake Union/Ship Canal storm drainage basins (see Figures 2-4 for sampling locations). Four other basins were examined, but insufficient amounts of sediment were present to warrant sampling. The remaining basins have smaller drainage areas and were not examined for sediment during the course of this study. To collect a sediment samle representative of the whole drainage basin, sediments were collected from either the terminal manhole or from the lowest dry manhole in each collection system. Each sediment sample was analyzed for total organic carbon and total sulfides. The results from those tests provide a general indication of pollutant loadings. Depending on the quantity of the remaining sample, analyses were performed for various metals. Arsenic, cadmium, chromium, copper and lead were analyzed as a minimum group because of their high toxicity and/or suspected presence in the sediments. Where enough sediment was available, testing was also performed for beryllium, mercury, nickel, zinc, silver, selenium, biological oxygen demand (DOD), and oil and grease.

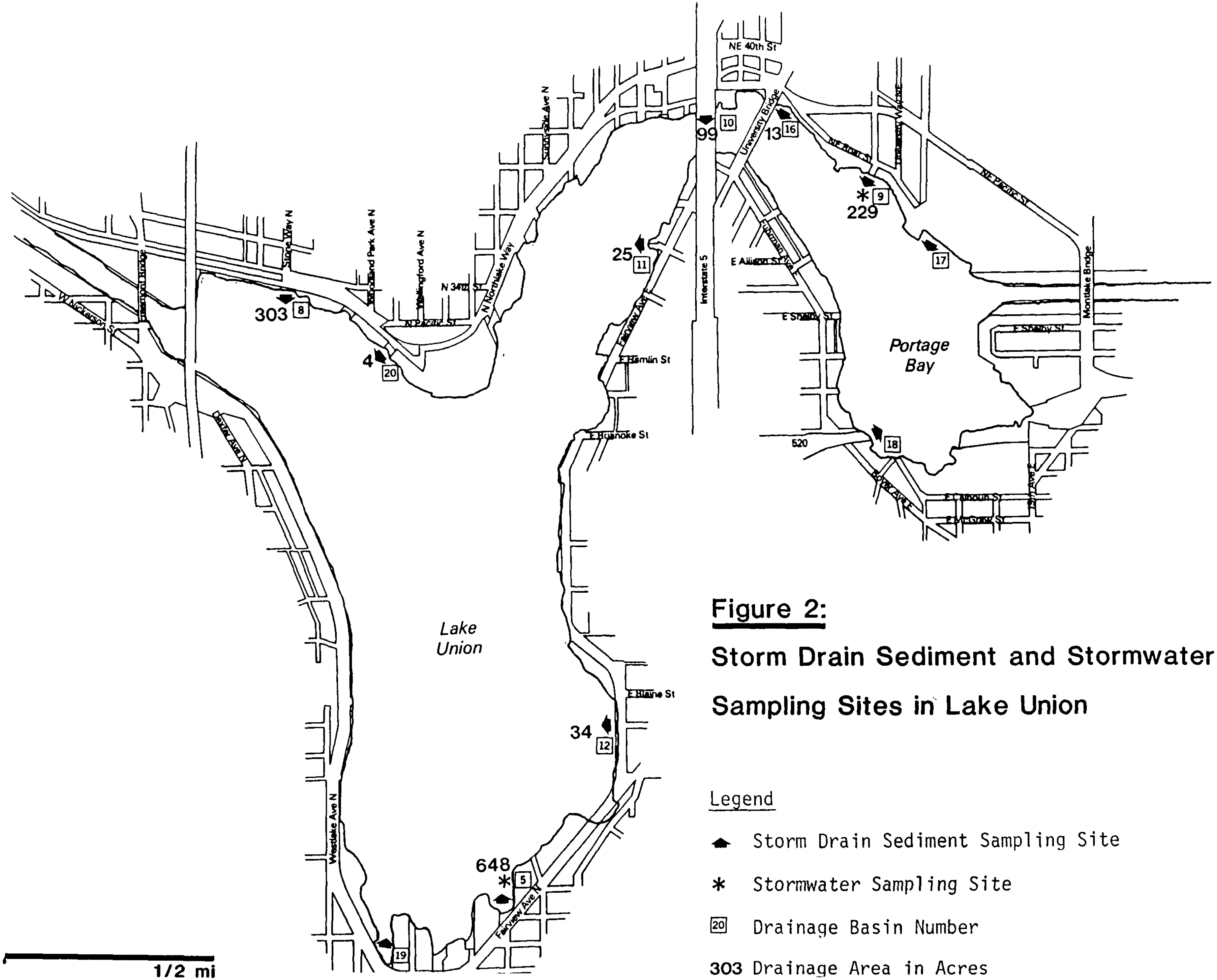


Figure 2:

Storm Drain Sediment and Stormwater Sampling Sites in Lake Union

Legend

Storm Drain Sediment Sampling Site

* Stormwater Sampling Site

20 Drainage Basin Number

303 Drainage Area in Acres

Figure 3:

Storm Drain Sediment and Stormwater Sampling Sites in the Ship Canal

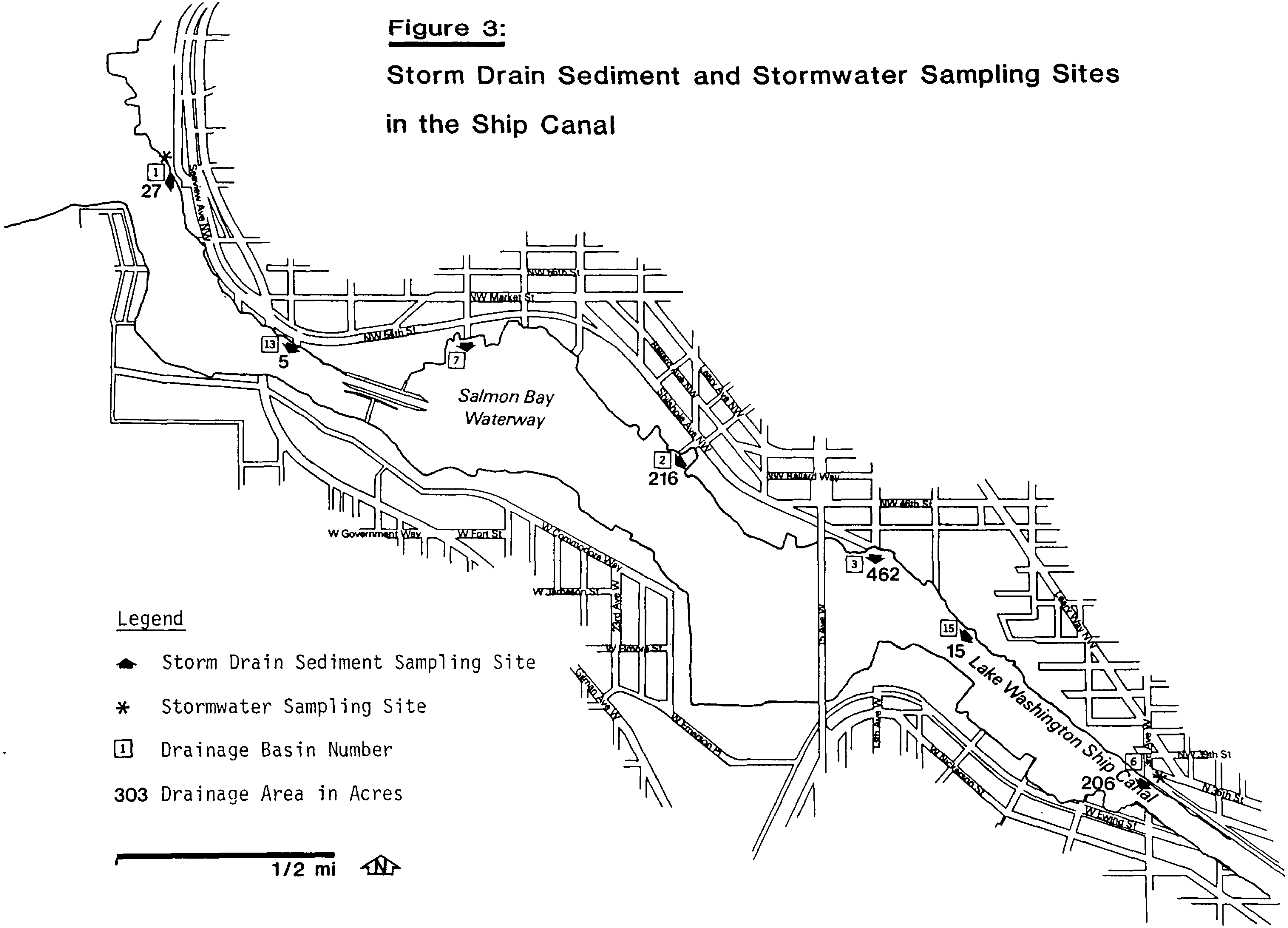
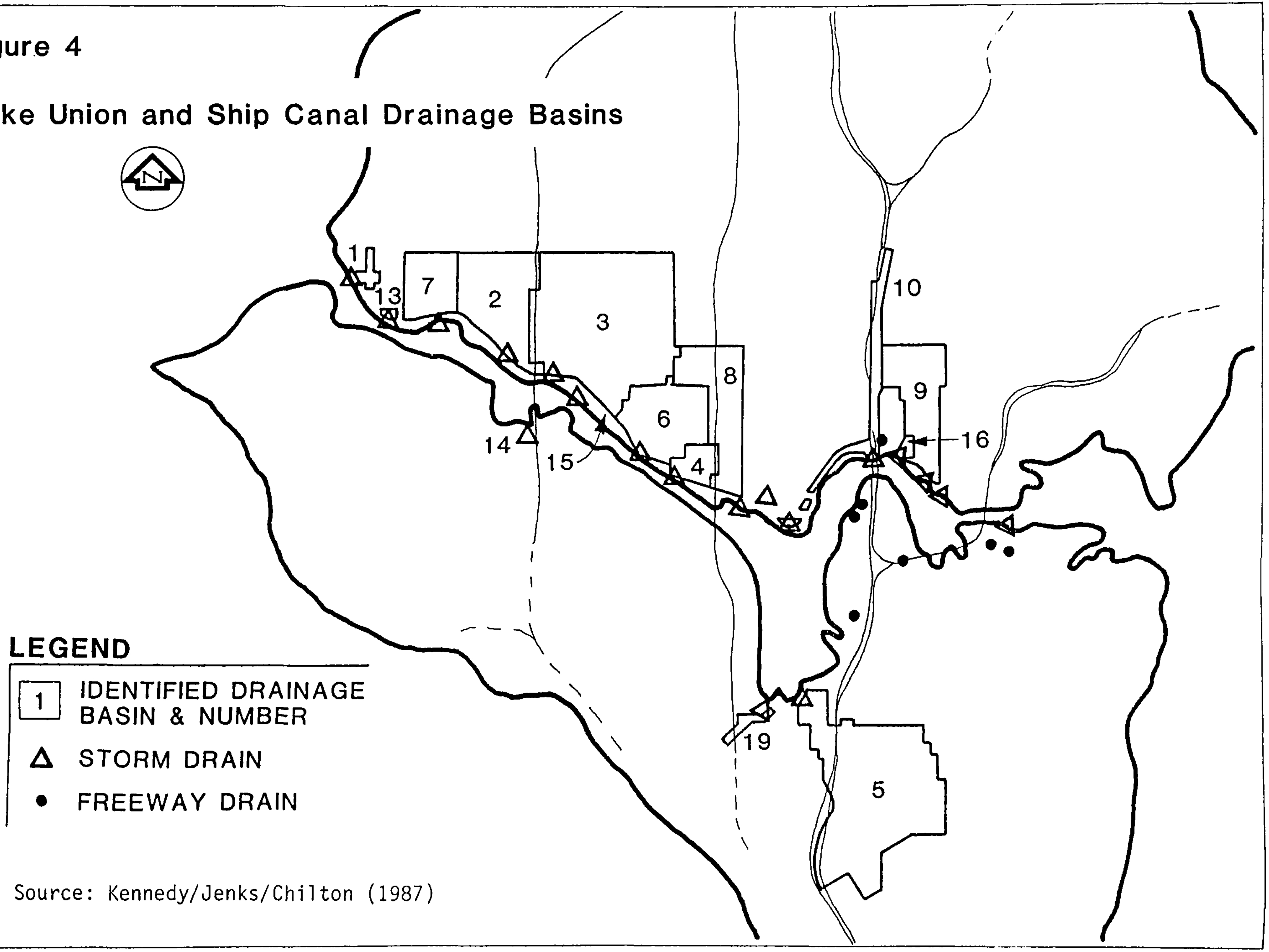


Figure 4

Lake Union and Ship Canal Drainage Basins



Source: Kennedy/Jenks/Chilton (1987)

Four basins (Basins 1, 5, 6 and 9 - see Figures 2-4) were monitored for stormwater flow. These basins are representative of the area that contributes runoff to Lake Union and the Ship Canal; various land uses are found. Composite stormwater samples were collected during eight storm events, two storms per drainage basin. In Basin 6, one stormwater sample was collected during a first flush event (10/25/86 - a rainstorm following long periods of dry weather) and the other was collected during a "typical" winter storm event, i.e., during a nearly continuous wet period. Samples from the other three basins were collected during two "typical" winter storms. Stormwater samples were analyzed for the same eleven metals as the storm drain sediments, conventional water quality parameters, total phenols, oil and grease, cyanides and base/neutral organic priority pollutants. In cases where not enough stormwater was available to conduct all analyses, priority was given to metals and nutrients analyses since these parameters were expected to be encountered in the greatest concentrations.

Storm Drain Sediment Analyses. Storm drain sediment sampling data is presented in Table 11. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc and silver were found in sediments from all drainage basins. Metals concentrations in storm drain sediments generally exceeded concentrations in sediments from the bottom of Lake Union and the Ship Canal. This was especially true for lead, nickel, cadmium, copper and zinc.

Sulfide content in sediments has been used as an indicator of conventional pollutant contamination in Puget Sound studies. Sulfides were detected in only two sediment samples (Basins 7 and 14) at levels just above detection limits. Although detection limits varied, it appears that conventional pollutant problems in storm drains may be limited when compared with concerns about toxic chemicals.

Oil and grease is an indicator of organic compounds, primarily heavy oils, animal and vegetable fats and greases; concentrations in the storm drain sediments ranged from 500 - 28,000 ppm. Samples exhibiting high oil and grease levels (Basins 2,6,7,14,15) were also analyzed for total petroleum hydrocarbons to assess the likely sources of the oil and grease. The total petroleum hydrocarbon analyses showed that the high oil and grease readings were obtained from long chain hydrocarbons, fats and greases, and/or heavier organic priority pollutants (e.g., PCBs).

Total organic carbon (TOC) is an indicator of organic compounds including heavy and lighter oils, organic priority pollutants and soils with organic materials. TOC concentrations ranged from 1,600 - 89,700 ppm, with only four of the eleven locations showing concentrations below 10,000 ppm. Both oil and grease and TOC ranges exceeded concentrations measured in bottom sediments of Lake Union and the Ship Canal.

Biological oxygen demand (BOD) is an indicator of microbial activity which may reduce oxygen content of waters and thus affect aquatic life due to oxygen depletion. BOD concentrations ranged from 220-7600 ppm, exceeding BOD concentrations in south Lake Union sediment samples at four of the six basins sampled.

TABLE 11
CONVENTIONAL SEDIMENT QUALITY PARAMETERS AND METAL LEVELS
IN LAKE UNION AND SHIP CANAL STORM DRAIN SEDIMENTS

BASIN NUMBER	LOCATION	BOD mg/Kg	TOC mg/Kg	Oil & Gr mg/Kg	Tot. S- mg/Kg	Arsenic mg/Kg	Beryllium mg/Kg	Cadmium mg/Kg	Chromium mg/Kg	Copper mg/Kg	Lead mg/Kg	Mercury mg/Kg	Nickel mg/Kg	Zinc mg/Kg	Silver mg/Kg	Selenium mg/kg
1	N.W. 60th and Seaview Ave NW	NA	20000	NA	<10	1700	7.3	16	53	210	1100	0.65	390	2800	NA	NA
2	20th Ave NW & Shilshole Ave NW	4000	12000	13000	<1	28	<0.28	3	93	560	920	0.478	70	1050	9.6	<0.3
3	14th Ave NW & Shilshole Ave NW	NA	30000	NA	<1	45	<0.8	8.5	62	22	1200	1.3	89	1400	NA	NA
6	3rd Ave NW & N 36th St.	7600	89700	17000	<1	81	<1	7.3	69	400	950	2.29	140	1700	3.4	3
7	28th Ave NW & NW Market St	NA	38000	25000	4.9	0.74	<0.4	3.9	35	290	700	0.45	47	740	0.78	0.23
10	I-5 & Northlake Wy NE	NA	7500	NA	NA	30	NA	0.96	350	260	2700	NA	NA	NA	NA	NA
13	34th Ave NW & N 54th St	NA	8750	NA	<2.5	140	0.41	39	19	260	2500	1.09	660	7600	NA	NA
14	16th Ave W & W Emerson Pl	5200	34500	28000	1.2	30	<0.25	5.8	49	490	500	0.362	32	700	1.2	0.98

BASIN NUMBER	LOCATION	BOD mg/Kg	TOC mg/Kg	Oil & Gr mg/Kg	Tot. S- mg/Kg	Arsenic mg/Kg	Beryllium mg/Kg	Cadmium mg/Kg	Chromium mg/Kg	Copper mg/Kg	Lead mg/Kg	Mercury mg/Kg	Nickel mg/Kg	Zinc mg/Kg	Silver mg/Kg	Selenium mg/kg
15	9th Ave NW & NW Fern PL	5000	29000	24000	<2.5	66	<0.4	1.7	270	1300	210	0.32	370	1000	1.9	<0.4
16	Eastlake Ave NE & NE Boat St	1040	6500	500	<2.5	110	0.15	3.3	31	80	450	0.165	110	360	1.5	<0.6
19	Broad St & Westlake Ave N	220	1600	640	<1	42	0.13	0.42	28	68	340	0.036	21	280	0.54	<0.3
AVERAGES																
	Storm Drain Sites	3843	25232	13518	3.1	207	2.0	8.2	96	358	1052	0.71	193	1763	2.4	2.0
	S. Lake Union[1]	2448	98	160	NA	30	NA	0.8	12	85	166	7.6	12	210	0.37	NA
	Lake Washington[2]	33.8	NA	0.69	39.6	35.7	137.2	NA	34.2	131.7	0.38	NA	NA	NA	NA	NA
	L. Union/Shp Cnl[2]	84	NA	1.3	49	124	334	NA	54	343	2.2	NA	NA	NA	NA	NA
	Ship Canal[3]	NA	NA	NA	NA	NA	0.4	5.6	48	50.5	60.9	0.4	46.7	NA	2	NA
	Duwamish River[3]	NA	NA	NA	NA	NA	0.8	9.0	42.0	95.8	187.0	0.3	31.9	NA	2.2	NA
	McAllister Creek[3]	NA	NA	NA	NA	NA	NA	<0.1	13.4	9.2	38	0.02	NA	NA	NA	NA

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TABLE 11 CONTINUED

INTERIM SEDIMENT QUALITY VALUES	BOD mg/Kg	TOC mg/Kg	Oil & Gr mg/Kg	Tot. S- mg/Kg	Arsenic mg/Kg	Beryllium mg/Kg	Cadmium mg/Kg	Chromium mg/Kg	Copper mg/Kg	Lead mg/Kg	Mercury mg/Kg	Nickel mg/Kg	Zinc mg/Kg	Silver mg/Kg	Selenium mg/Kg
Great Lakes Dredged Sediments[4]	NA	NA	NA	NA	10	NA	1.0	100	100	50	0.1	100	100	NA	NA
Puget Sound Benthic Apparent Effects Threshold[5]	NA	150000	NA	NA	85	>0.5	5.8	59	310	300	0.88	49	260	5.2	>63

NA = Not Available

Source: Kennedy/Jenks/Chilton. 1987

Sources of comparative data for this table are:

[1]South Lake Union Pilot Project Report. 1986.

[2]Galvin, et al. 1984.

[3]McCain, et al. 1982.

[4]Report of the Technical Subcommittee on Determination of Dredge Material Suitability for In-Water Disposal. 1985.

[5]Tetra Tech, Inc. 1986.

Stormwater Analyses. Stormwater sampling data is presented in Table 12. There is higher pollutant loading during a first flush storm than during a typical winter storm event. For example, conventional pollutant concentrations were up to six times greater for the first flush event in Basin 6. Metals concentrations were one to three orders of magnitude greater for the first flush event when compared with typical winter storm events.

Lake Union drainage basin stormwater is generally less contaminated than stormwater in other cities with populations similar to Seattle. However, as shown in Table 12, lead and copper concentrations in stormwater entering Lake Union and the Ship Canal exceeded acute water quality criteria (for protection of aquatic life) for all storms. Arsenic, cadmium, zinc and cyanide levels exceeded acute water quality criteria to a lesser degree, but the first flush storm accounted for the majority of these exceedances. Therefore, it appears that lead and copper are the contaminants of concern for long-term degradation of lake quality and impact on aquatic biota.

Basin 1 (Seaview N.W.) generally exhibited lower concentrations of pollutants in stormwater (except for arsenic, cadmium and total dissolved solids) than the other three basins. Low concentrations of most pollutants may be due to the lack of industrial sources upstream of the sampling location or because roadways are not heavily travelled. Pollutant concentrations in stormwater from Basin 5 (Minor Avenue N.) were similar to other basins. Concentrations of zinc and total phenols were slightly higher compared with other basins, possibly due to highway runoff and industrial sources within the basin. Total phosphorus and lead concentrations were slightly higher in Basin 6 (3rd Avenue N.W.) than in other basins. Upstream residential sources may account for the elevated levels of total phosphorus. High industrial use and heavy vehicle use roads near the sampling location may account for higher lead levels. Most pollutant parameters in Basin 9 (Brooklyn Avenue N.E.) were similar to winter storms from other basins.

Estimates of Mass Loadings. Mass loadings of stormwater pollutants to Lake Union and the Ship Canal were estimated, using runoff volumes generated with a computer model and average concentrations of pollutants in stormwater samples obtained during this study. Table 13 presents estimates of total loadings from all storm drain outfalls in the study area for several water quality parameters, for both the 10-year storm and average annual discharges. Estimated annual pollutant loadings from the four basins in which flow monitoring and sampling were conducted are presented in Table 14. Basin 6 is estimated to discharge the highest loading per acre of heavy metals; Basin 9 is estimated to contribute the highest loading per acre of total dissolved solids.

In general, metals concentrations in storm drain sediments were elevated compared with interim criteria for freshwater and salwater environments (see Table 11). Although heavy metals from sediments may be continuing to degrade Lake Union, the relative contribution of storm drain sediments to Lake Union sediments appears minor. Most basins where sediments were sampled contained relatively low volumes of sediments which would be available for transport into the Lake. In addition, stormwater quality data obtained during this study indicate low solids concentrations in stormwater runoff from both the first flush winter storm and average winter storm.

TABLE 12

CONVENTIONAL WATER QUALITY PARAMETERS AND METAL LEVELS IN STORMWATER DISCHARGED TO LAKE UNION AND THE SHIP CANAL[1]

BASIN NUMBER	LOCATION	Coliforms MPN/100ml	BOD mg/l	TSS mg/l	TDS mg/l	Oil & Grease mg/l	TKN mg/l	Total P mg/l	Arsenic mg/l	Cadmium mg/l	Chromium mg/l	Copper mg/l	Lead mg/l	Mercury mg/l	Nickel mg/l	Zinc mg/l
1	N.W 60th &			7.3	54	<2	0.84	0.14	0.01	0.003	0.002	0.01	0.01	<0.0002	<0.01	0.1
	Seaview N.W.			8.3	230	<2	0.63	0.1	<0.01	<0.002	0.005	<0.01	<0.01	<0.0002	0.01	0.04
5	Minor Ave.	1600	22	150	63	5.9	1.9		<0.01	<0.0064	0.021	0.07	0.1	0.0006	<0.01	0.3
	N. & Fairview			220	50	7	1.8	0.06	<0.01	0.002	0.02	0.09	0.08	0.0003	<0.01	0.49
	Ave.															
6	3rd Ave.			220	76	2.1	1.8	0.04	0.54	0.13	0.11	1.4	6	0.0004	0.42	10.1
	and N. 36th			51	79		2.9	0.21	0.006	<0.01	<0.02	0.06	0.2	<0.0001	<0.05	0.27
	St.															
9	Brooklyn Ave.			120	604	3.2	1.2	0.11	0.002	<0.01	<0.02	0.02	<0.1	<0.001	<0.05	0.19
	N.E. & Boat	1600	26			6.8	3.3	0.01	<0.01	<0.0024	0.03	0.05	0.15	0.0004	<0.05	0.31
	St.															
Freshwater Acute Criteria									0.36	0.004	1.70	0.018	0.082	0.002	1.8	0.32
Freshwater Chronic Criteria									0.19	0.001	0.21	0.012	0.003	.000012	0.096	0.047

BOD = biological oxygen demand
TSS = total suspended solids
TDS = total dissolved solids
TKN = total Kjeldahl nitrogen
Total P = total phosphorus

[1] Stormwater samples were collected during two storms per drainage basin; hence two numbers are shown for most parameters per basin.

Source: Kennedy/Jenks/Chilton. 1987.

TABLE 13

ESTIMATED TOTAL LOADINGS
FROM STORMWATER DISCHARGE (ALL OUTFALLS)
TO LAKE UNION AND THE SHIP CANAL

Water Quality Parameter	Average Concentration (mg/1)	Estimated Total Loading (kg)	
		10-Year Storm	Median Year
Total Discharge (million gallons)	not applicable	107.3	1,434
Biological Oxygen Demand	24	9,750	130,300
Total Suspended Solids	111	45,100	602,500
Total Dissolved Solids	165	67,000	895,600
Oil and Grease	5.0	2,030	27,150
Total Kjeldahl Nitrogen	1.8	731	9,770
Total Phosphorus	0.10	41	543
Arsenic	0.14	57	760
Cadmium	0.05	20	271
Chromium	0.03	12	163
Copper	0.24	98	1,300
Lead	1.09	443	5,920
Mercury	0.0004	0.2	2
Nickel	0.22	89	1,090
Zinc	1.47	597	7,979
Total Metals	2.77	1,130	15,040
Total Organic Halogens	0.04	16	217
Total Phenols	0.009	4	49

209-792.T13

TABLE 14

ESTIMATED ANNUAL LOADINGS
FROM MONITORED BASIN OUTFALLS
TO LAKE UNION AND THE SHIP CANAL

Water Quality Parameter	Estimated Total Annual Loading (kg/ac/yr)			
	Basin 1 (Ship Canal)	Basin 6 (Ship Canal)	Basin 5 (Lake Union)	Basin 9 (Portage Cut)
Total Discharge (million gallons/ acre/year)	0.65	0.50	0.54	0.54
Biological Oxygen Demand	NA	NA	45.3	53.6
Total Suspended Solids	19.2	258	381	247
Total Dissolved Solids	350	14.8	117	1,250
Oil and Grease	ND	4.0	13.4	0.89
Total Nitrogen	1.8	4.5	3.9	4.7
Total Phosphorus	0.29	0.06	0.06	0.12
Total Heavy Metals	0.29	18.2	1.2	0.78
Total Organic Halogens	ND	NA	0.10	0.02
Total Phenols	0.004	0.02	0.03	0.01

Note: ND = Parameter not detected in stormwater from that basin.

NA = Data not available for that basin.

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Ranking of Basins. In order to establish priorities for future action, the storm drain basins were ranked based on their relative contributions of stormwater flow and pollutant loadings to Lake Union and the Ship Canal. Table 15 indicates the rankings according to percent of annual runoff and pollutant loading. Based on this data, it appears that efforts to control stormwater volumes and pollutant loading would be most effective in the larger basins such as Basins 3 and 5, and in the medium-sized basins which exhibited the highest pollutant concentrations, including Basins 2, 6, 7 and 9. Basins 13, 14 and 15 are also good candidates for investigation of source control actions. Although these basins do not contribute large volumes of runoff, the sediments from these basins indicate potentially highly concentrated sources of pollutants.

Followup Source Evaluation/Potential Source Control Measures. A followup source evaluation is currently underway to determine from which industrial or other shoreline uses the storm drain contaminants have come. Potential source control measures that may be feasible for implementation within one or more of the sub-basins draining into Lake Union and the Ship Canal include: street sweeping, public education (about potential environmental hazards of disposal of household chemicals to storm drains), National Pollutant Discharge Elimination System (NPDES) permits for industrial discharges to storm drains, stormwater collection system maintenance measures, vigorous enforcement of erosion control regulations, and surface runoff control measures (e.g., grass swales, ponding basins).

Lake Union and Ship Canal Outfall Survey (Environmental Intern Program and Seattle Engineering Department)

In summer - fall 1986, Environmental Intern Program (EIP) volunteers conducted a boat survey of outfalls discharging into the north end of Lake Union, the north end of Portage Bay, and the Ship Canal (Figures 5 and 6). One hundred fifty outfalls were identified and classified by the EIP volunteers as storm drains, sewer drains, seeps or "other, unidentified". Owners/occupants of land near the outfalls included the City of Seattle, University of Washington, Seattle Pacific University, houseboat owners, other home owners, yacht clubs, marinas, shoreline industries and commercial establishments. The data from the outfall survey will be evaluated by SED to track sources of runoff into Lake Union and the Ship Canal. The data will also be included in maps in the application materials for NPDES storm drain permits.

Combined Sewer Overflow Abatement Planning (Seattle Engineering Department)

In 1985 the Washington state legislature passed a bill requiring dischargers to prepare and submit by January 1, 1988, plans for achieving "...the greatest reasonable reduction in combined sewer overflows at the earliest possible date...". The City has already developed plans for reducing combined sewer overflows (CSOs) which discharge into Longfellow Creek, Lake Washington and the recreational saltwater beaches around Alki and Magnolia. The main focus of the current City CSO planning effort will be on Lake Union and the Ship Canal (as well as Elliott Bay and the Duwamish).

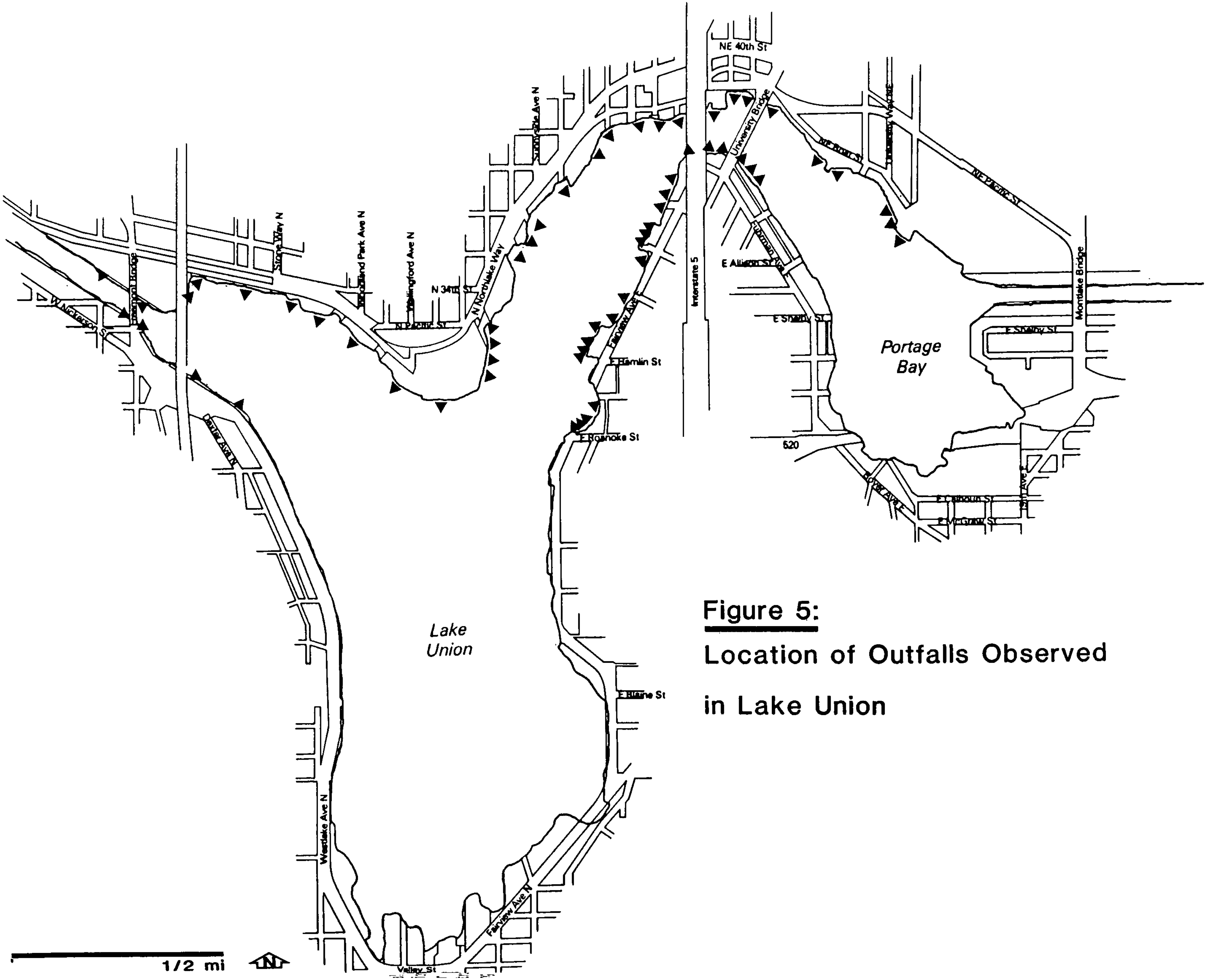

Figure 5:
Location of Outfalls Observed in Lake Union

Figure 6:

Location of Outfalls Observed in the Ship Canal

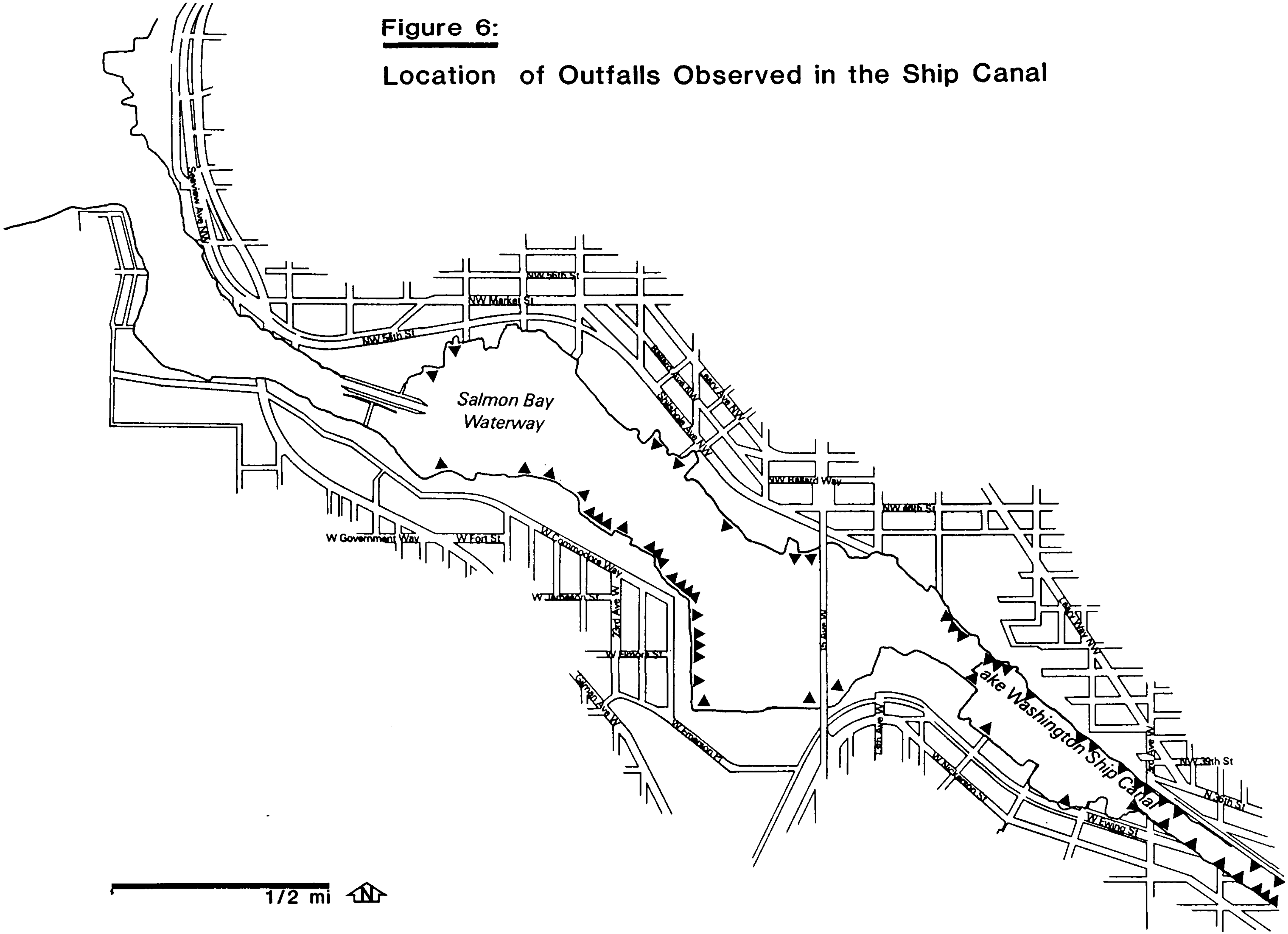

TABLE 15

RANKING OF STORM DRAIN BASINS BY PERCENT OF TOTAL ANNUAL RUNOFF AND BY POLLUTANT LOADING

Basin Number	Connected Drainage Area (acres)	Percent of Total Annual Runoff
3	635.3	22.5
5	555.4	21.0
2	234.2	9.4
8	230.5	8.6
9	212.4	8.1
6	190.5	6.7
7	170.3	6.1
10	104.4	4.7
4	61.1	2.6
11	36.5	2.0

Parameter	Highest Concentrations in Sediments
Metals (lead, nickel, zinc, arsenic, cadmium)	Basins 1, 2, 3, 13, 15
Oil and Grease	Basins 7, 14, 15, 2, 6
TOC	Basins 6. 7, 14, 15
BOD	Basins 6, 14, 15, 2
	Highest concentrations in Stormwater
TDS	Basins 1, 9
Metals	Basin 1 (arsenic, cadmium) Basin 5 (zinc) Basin 6 (lead)
TOX, phenols	Basin 5

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The Seattle Engineering Department is developing criteria that will be used in ranking alternatives for reducing CSO discharges, e.g., complete separation of sanitary sewage and stormwater, partial separation, storage, transfer, drainage ordinance modifications, operational modifications, best management practices, and on-site treatment and discharge. In addition to analyzing costs and benefits of the various CSO reduction alternatives, net pollutant loading and receiving water sensitivity to CSOs will also be analyzed. Sediment samples have been taken near several CSO outfalls in Lake Union. The samples are currently being analyzed for conventional sediment quality parameters (e.g., oil and grease, total organic carbon), metals and organic priority pollutants. Data is forthcoming from this task and other tasks that comprise the development of the City's plan for reducing CSO discharges. For more information on the scope of the planning effort see Combined Sewer Overflow Plan (1986).

University Regulator CSO Control Project (Metro)

The Greenlake/I-5 University Regulator CSO discharges the largest annual volume of combined sewage and stormwater to fresh water (Portage Bay) in the Seattle area. Metro is currently evaluating alternatives for diverting stormwater from the combined sewer system including: 1) a new storm drain discharging into the University Slough at Union Bay, and 2) a new storm drain discharging into the Ship Canal near the I-5 Bridge. Both of these would involve a significant reduction in combined sewer overflows at the University Regulator CSO. Potential water quality impacts as a result of sewer separation include: 1) eutrophication impacts such as changes to algal abundance and effects on water clarity, 2) microbiological impacts such as changes in indicator organisms (fecal coliforms) and potential human health effects, and 3) toxicant impacts such as changes in the concentration of toxic chemicals and potential aquatic organism effects.

Definition of existing water quality conditions is necessary for impact assessment with respect to the three types of water quality impacts. Water quality was sampled biweekly (eleven times) at six sites in the Ship Canal, Lake Union, and Portage Bays from June through November, 1986. Water was tested for eutrophication indicators (nutrients, chlorophyll-A, water clarity), the microbiological indicator (fecal coliforms) and toxicant indicators (metals). Sediment samples were collected in November, 1986 from eight sites. Sediments were tested for toxicants (metals and trace organics) and benthic invertebrates. Summarized below are water quality, sediment chemistry and benthic infauna data obtained from the sampling sites (see Figure 1 for location of sampling sites).

Water Quality. All six Portage Bay/Lake Union/Ship Canal sites were low in algae abundance and exhibited moderate to good water clarity (Table 16). All sites were considered oligo-mesotrophic with respect to chlorophyll-A and mesotrophic with respect to Secchi disk transparency.

Washington State fecal coliform criteria (50 organisms/100 ml) were exceeded on at least some sampling dates at all six sites (Table 16), ranging from two out of eleven sampling dates at the University Regulator CSO site in Portage Bay to all eleven sampling dates at the Ship Canal site near the Fremont Bridge. There was an increase in the fecal coliform count in a westward direction. Since fecal coliform counts at the most downstream sites (Stone Way and Ship Canal, near Fremont Bridge) were consistently high throughout the summer, sources other than stormwater or combined sewer overflows might be suspect (possibly discharge of sewage and bilge from summer boat traffic).

Metal levels were compared with the most recent (1986) EPA water quality criteria for protection of aquatic life (Table 16). These criteria are defined for acute toxicity (levels not to be exceeded at any time) and chronic toxicity (average concentration limits not to be exceeded over a 24 hour period). None of the metal levels exceeded acute toxicity criteria with the exception of silver on one sampling date at the University Regulator CSO sampling site.

Silver levels (0.3-4.2 ppb) exceeded chronic toxicity criteria (0.12 ppb) on all sampling dates at all six sampling sites. This means that silver levels were high enough to cause long-term adverse health effects to aquatic biota at these six locations. Zinc levels also exceeded chronic toxicity water quality criteria (47 ppb) at the Lake Union/Gas Works Park site (64 ppb) on two out of the eleven sampling dates.

Metal levels were also compared with the most recent (1986) EPA water quality criteria for protection of human health (Table 16). These criteria are based on daily drinking of two liters of surface water from a river or stream (minimally treated non-municipal supply). The nickel level in the water column at the I-5 Bridge site (15 ppb) exceeded human health criteria (13.4 ppb) on one sampling date. Arsenic levels (1-6 ppb) exceeded these criteria (0.0022 ppb) at all sampling sites and on all sampling dates. The human health criteria value presents the 1 in 1,000,000 risk level for arsenic as a carcinogen; i.e., for every 1,000,000 people who drink two liters of water daily throughout their lives with arsenic levels of at least 0.0022 ppb, one person could get cancer. The 0.0022 ppb level is based on a "standard" human weight of 70 kilograms (154 lbs.) and a "standard" human life span of 70 years.

Sediment Chemistry. Conventional sediment quality parameters are presented in Table 17. All eight sediment sampling sites had total phosphorus values (676.2 - 1176.9 ppm) indicative of "heavily polluted sediments" based on criteria by Engler (1980). Oil and grease levels (ranging from 2.59 - 4311 ppm) were highest in the sediment samples from south Portage Bay, Portage Bay near the Queen City Yacht Club, and Lake Union near the City Light Steam Plant. These levels were compared with interim criteria developed by the Puget Sound Dredged Disposal Analysis (PSDDA) Program for unconfined open water disposal of dredged material in saltwater. Levels at six of the eight sampling sites exceeded the 500 ppm PSDDA "precaution level". At five of these six sites, oil and grease levels exceeded 1000 ppm, which is the level that requires analysis of dredged materials for priority pollutants before the materials are approved for disposal. Total organic carbon (TOC) levels ranged from 2.6 percent at the University Regulator CSO site to 13.3 percent at the Portage Bay site near the Yacht Club. TOC levels in sediment samples from all eight sites were below the 15 percent AET value established for Puget Sound sediments.

TABLE 16

WATER QUALITY PARAMETERS AND METAL LEVELS[1]/ IN PORTAGE BAY, NORTH LAKE UNION AND THE SHIP CANAL

Parameter/Metal	Portage Bay	UW Regulator	I5 Bridge	Lake Union/ Gas Works Park	Stone Way	Ship Frem Bri
Dissolved Oxygen						
Surface	9.2 (8.7,10.4)	8.9 (7.7,9.8)	8.5 (7.9,9.3)	8.6 (7.2,9.4)	8.4 (7,10)	8.3 (6.8,
10 meters	9.1 (8,10.4)	8.8 (8.2,10)	7.9 (5.9,9.5)	6.6 (1.4,9.9)	6.5 (3.2,10.1)	7.0 (3.5,
Conductivity (umho/cm)						
Surface	94.2 (86,100)	95.3 (85,100)	108.2 (84,180)	158.4 (90,315)	178.3 (91,360)	189.9 (94,3
10 meters	93.6 (87,100)	95.8 (85,120)	116.7 (90.180)	292.8 (96,560)	327.3 (100,640)	324.4 (94,8
Turbidity (NTU)						
Surface	1.1 (0.9,1.4)	1.1 (1,1.2)	1.1 (0.1,1.6)	1.0 (0.1,1.3)	1.2 (0.9,1.6)	1.2 (0.9,
10 meters	1.4 (1,2.4)	1.1 (0.1,1.4)	1.5 (1.2,1.8)	1.4 (1.2,1.8)	1.4 (1,1.9)	1.4 (1.1,
Fecal Coliforms						
Surface	75.1 (2,540)	28.2 (2,110)	52.3 (7,240)	170.5 (17,920)	674.6 (8,2400)	591.8 (70,1
Arsenic (360/190/0.0022)	1.5 (1,3)	1.3 (1,3)	1.7 (1,3)	1.6 (1,3)	1.8 (1,6)	1.75 (1,3.
Cadmium (3.9/1.1/10)	0.11 (0.1,0.2)	0.21 (0.1,1.2)	0.16 (0.1,0.7)	0.14 (0.1,0.4)	0.1 (0.1,0.1)	0.1 (0.1,
Chromium (16/11/50)	1.2 (0.5,5.5)	1.1 (0.5,4.4)	1.1 (0.5,4.3)	1.2 (0.5,4.4)	0.8 (0.5,2.5)	1.3 (0.5,
Copper (18/12/NA)	1.5 (1,3)	1.5 (1,3)	2 (1,3)	3.9 (1,10)	2.4 (1,3)	3.8 (1,9)
Lead (82/3.2/50)	1.4 (1,3)	1.6 (1,5)	2.5 (1,16)	2.5 (1,12)	1.4 (1,4)	1.9 (1,10
Nickel (1800/96/13.4)	1.8 (1,5)	1.1 (1,2)	2.4 (1,15)	1.6 (1,7)	1.1 (1,2)	3.4 (1,13
Silver (4.1/0.12/50)	0.3 (0.3,0.6)	1 (0.3,4.2)	0.4 (0.3,0.9)	0.4 (0.3,1.1)	0.5 (0.3,1.5)	0.7 (0.3,
Zinc (320/47/5000)	12 (10,22)	15.2 (10,25)	14.5 (10,32)	24.5 (10,64)	16.9 (10,35)	14.3 (10,3

All values are expressed as mg/l(ppm) unless otherwise indicated.

NA = not available.

[1]Numbers in parentheses after each metal represent freshwater criteria for acute toxicity to aquatic life, chronic toxicity to aquatic life, and human health protection. For each site, average value is given for July-November 1986 with the range of observed values in parentheses.

Source: Anderson, et al. 1987.

209-792.T16

TABLE 17
CONVENTIONAL SEDIMENT QUALITY PARAMETERS AND SEDIMENT TOXICANT LEVELS[1,2] IN PORTAGE BAY, NORTH LAKE UNION AND THE SHIP CANAL

Parameter	Sampling Site							
	South Portage Bay	Portage Bay near Yacht Club	University Regulator CSO	Portage Bay off park	North Lake Union	Lake Union near Steam Power Plant	Mid Lake Union	Ship Canal at Fremont
Depth (meters)	1.5	7	5	4	8	6	12	12
Appearance (grain type, color, presence of plants, presence of odor)	silt/mud grey, plants	silt/mud black, natural odor	Sand/silt mud, grey, plants, slight H_2S odor	Silt/mud/ sand, black	silt/mud/ sand, brown	silt/mud, black, petroleum odor	silt/mud, black, natural odor	sand/silt/ mud, black, slight H_2S odor
Total Phosphorus	961.5	845.5	1124.2	1176.9	676.2	1133.3	1146.7	841.5
Total Oil & Grease	2969	3509	329	1492	886	4311	1213	259
Hydrocarbon Oil and Grease	1246	1336	313	1492	781	3978	1213	259
Total Organic Carbon (%)	7.6	13.3	2.6	11.6	6.0	4.7	5.5	3.1
Metals								
Silver (5.2)	ND	ND	ND	ND	ND	ND	6.7*	1.5
Aluminum (NA)	21307.7	12727.3	8032.3	13076.9	12619.0	13888.9	27600.0	17707.3
Arsenic (85)	12.3	5.5	2.4	3.8	ND	22.2	40.0	51.2
Cadmium (5.8)	3.1	3.6	0.5	3.1	ND	3.1	4.0	2.2
Chromium (59)	65.4*	39.1	25.8	46.9	39.0	60.0*	82.7*	57.1
Copper (310)	112.3	83.6	42.7	110.8	107.6	280.0	346.0*	199.3
Iron (37000)	23076.9	16363.6	10387.1	17538.5	17714.3	36444.4	39866.7	27804.9
Manganese (1000)	273.8	322.7	160.3	314.6	349.0	477.8	439.3	300.0

Parameter/Toxicant	Sampling Site: South Portage Bay	Portage Bay near Yacht Club	University Regulator CSO	Portage Bay off park	North Lake Union (near I5)	Lake Union near Steam Plant	Mid Lake Union	Ship Canal at Fremont Bridge
Metals								
Nickel (49)	69.2*	45.5	30.6	46.2	42.9	208.9*	80.0*	51.2*
Lead (300)	230.8	254.5	122.6	423.1*	261.9	1108.9*	680.0*	414.6*
Tin (NA)	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (260)	334.6*	187.3	86.3	273.1*	227.1	822.2*	572.7*	358.5*
Polycyclic Aromatic Hydrocarbons								
Fluorene (6.40)	ND	0.04	0.03	ND	2.5	0.77	0.45	11.1*
Naphthalene (2.10)	ND	ND	ND	ND	ND	0.77	0.82	11.6*
Acenaphthene (0.50)	ND	ND	0.03	0.11	1.7*	ND	0.70*	18.1*
Acenaphthylene (0.64)	ND	ND	ND	ND	1.1*	ND	0.73*	0.78*
Anthracene (1.30)	ND	ND	0.06	0.30	8.4*	1.2	0.77	6.5*
Phenanthrene (3.20)	0.37	0.43	0.26	1.5	15.9*	5.1*	2.3	23.4*
Fluoranthene (6.30)	0.61	0.77	0.36	2.7	1.9	7.2*	5.8	20.6*
Pyrene (7.30)	0.72	0.90	0.36	2.6	19.7*	6.9	6.9	18.7*
Chrysene (6.70)	0.31	0.34	0.18	1.1	8.4*	3.3	2.5	7.2*
Benzo(a)anthracene (4.50)	0.21	0.32	0.14	0.83	6.8*	2.3	2.0	6.1*

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TABLE 17 (CONTINUED)

	Sampling Site							
	South Portage Bay	Portage Bay near Yacht Club	University Regulator CSO	Portage Bay off park	North Lake Union	Lake Union near Steam Plant	Mid Lake Union	Ship Canal at Fremont Bridge
Polycyclic Aromatic Hydrocarbons								
Benzo(a)pyrene (6.80)	ND	0.38	0.15	1.1	6.6	2.4	3.3	5.5
Benzo(b)fluoranthene (8.00)	ND	0.27	0.12	1.2	10.3*	3.3	2.7	7.4
Benzo(k)fluoranthene (8.00)	ND	0.39	0.16	1.1	5.9	3.5	2.9	8.3*
Indeno-1,2,3-CD-pyrene (5.20)	ND	ND	0.13	1.1	3.1	ND	2.2	4.8
Dibenzo(a,h)-anthracene (1.20)	ND	ND	0.03	0.23	0.72	0.68	0.73	0.46
Benzo(g,h,i)perylene (5.40)	ND	ND	0.14	1.1	4.7	2.0	3.1	6.1*
Polychlorinated Biphenyls (total) (1.10)	ND	ND	0.44	0.09	ND	ND	ND	ND

Three replicates from each sampling site were composited, completely mixed, subsampled and analyzed.

[1]Levels are expressed as mg/kg (ppm) dry weight unless otherwise noted. ND = Not Detected. NA = Not Available.

[2]Interim benthic apparent effects threshold (AET) values for Puget Sound sediments are given in parentheses for each toxicant. Asterisked numbers are those that exceed benthic AETs.

Source: Anderson, et al. 1987.

Results of sediment metals analyses are shown in Table 17. Twelve metals were tested; aluminum, arsenic, cadmium, chromium, copper, iron, manganese, nickel, lead and zinc were found consistently in most samples. Tin was not detected in any of the samples; silver was not detected in 85% of the samples.

Sediment sites ranged from relatively clean to heavily contaminated. The existing University Regulator CSO site ranked lower in concentration than most other sites for most parameters. In comparison, the potential stormwater discharge site in the Ship Canal at the I-5 bridge had consistently higher concentrations for most parameters. The mid-Lake Union site was generally the highest in concentration for most metals; interim benthic AET values for Puget Sound sediments were exceeded here for silver, chromium, copper, nickel, lead and zinc. Nickel, lead and zinc levels exceeded benthic AETs for Puget Sound sediments in samples from the Ship Canal near the Fremont Bridge and Lake Union near the City Light Steam Plant. Chromium levels also exceeded the benthic AET at the City Light Steam Plant site. None of the metal levels exceeded benthic AETs at any of the Portage Bay sites (with the sole exception of chromium levels in south Portage Bay sediments).

Results of trace organics analyses are also shown in Table 17. Thirty trace organic compounds were found, primarily PAHs, PCBs and phthlalate esters (plasticizers). Portage Bay sampling sites (including the University Regulator CSO site) had lower concentrations of trace organics than Lake Union and downstream Ship Canal sampling sites. The sampling site in the Ship Canal at the Fremont Bridge had the largest number of organic compounds and generally the highest concentrations. Twelve out of sixteen PAHs were found here at levels exceeding benthic AETs for Puget Sound sediments. The potential new storm drain discharge site near the I-5 bridge also had high concentrations of PAHs, in some cases similar to those at the Ship Canal/Fremont Bridge site. Nine out of twelve PAHs were found here at levels exceeding benthic AETs for Puget Sound sediments. No PAHs were found at levels exceeding benthic AETs at any of the Portage Bay sampling sites. Since PAHs are formed by incomplete combustion of fossil fuels, (e.g., coal used in the gasification process at the former Seattle Gas Plant), it is not surprising to find higher levels of PAHs in areas downstream from Gas Works Park.

In the absence of established criteria for health hazards in freshwater caused by contact with polluted sediments, it is difficult to interpret the meaning of the sediment chemistry data other than that there are relatively clean sediments in Portage Bay and heavily contaminated sediments in the tested areas in Lake Union and the Ship Canal. EPA's proposed benthic AET values for Puget Sound sediments were used for comparative purposes to determine which sediment sites were heavily contaminated. Benthic AET values have not been proposed for fresh-water sediments. The Puget Sound numbers may or may not be applicable to Lake Union benthic infauna. Furthermore, sediment toxicant levels below the Puget Sound benthic AET values are not necessarily "safe" for Lake Union benthic infauna.

As indicated in an earlier section of this report, Yake et al. (1986) found that heavily contaminated sediments from Lake Union were toxic to a freshwater amphipod species. Sediment metal concentrations documented for the University Regulator CSO Control Project are similar to the concentrations found by Yake, et al., but PAH concentrations reported by Yake et al. were two to three orders of magnitude higher than detected in the University Regulator CSO Control Project sediment samples.

Benthic Infauna. Table 18 presents mean total abundance (animals/m^2 of sediment from three replicates) and species richness (number of taxonomic groups/sampling site) of benthic infauna at each of the eight sediment sampling sites, and the ten most abundant taxonomic groups for all sampling sites. The University Regulator CSO outfall site and the south Portage Bay site had the highest abundance of benthic infauna (12,613 and 46,884 animals respectively); the mid-Lake and Ship Canal/Fremont Bridge sites had the lowest abundance (588 and 1319 animals respectively). Possible factors contributing to the greater abundance of animals in Portage Bay sediments are relatively low sediment toxicant levels and shallow sampling sites (Table 17). There may be less saltwater intrusion and higher DO levels at shallow sites (Table 13). Conversely, possible factors contributing to the relative paucity of animals in mid-Lake and Ship Canal sediments are: relatively high sediment toxicant levels and deep sampling sites (Table 17); there may be greater saltwater intrusion and lower DO levels at the deeper sites (Table 16).

Species richness showed the same trend as total abundance, i.e., more taxonomic groups were found in Portage Bay sediments than in Lake Union or Ship Canal sediments. Average species richness ranged from 3.7 groups at the Ship Canal/Fremont Bridge site to 22.3 groups at the Portage Bay/Yacht Club site (Table 18). In addition to members of taxonomic groups, types of animals also varied among sampling sites: Lake Union and Ship Canal sites were dominated by oligochaetes as was the case with the south Lake Union sites described earlier in this report. Taxonomic group differences were apparent between the existing CSO site and the potential stormwater discharge site at the I-5 Bridge. The existing CSO site tended to have more pollutant-tolerant groups.

Gas Works Park Groundwater Analysis Program (Seattle Parks Department and U.S. Geological Survey)

This program was designed to determine if groundwater under and around Gas Works Park is contaminated with toxic chemicals (from the former Seattle Gas Plant) and is migrating into Lake Union. In summer 1986, a seismic refraction survey was conducted to obtain data on the geohydrologic setting of the park, e.g., soil types and water table location. This data was used to determine where to drill test wells. In fall 1986, sixteen test wells were drilled (fifteen wells in Gas Works Park and one well outside the Park boundary) and groundwater samples were collected. Results of the groundwater analyses will be available in spring 1987. Parameters measured at all wells include: water temperature, pH, DO, conductivity, and levels of cyanide, PAHs and metals (arsenic, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc). Groundwater samples obtained from six of the wells inside the Park and the one well outside the park will also be analyzed for pesticides, PCBs and volatiles (monoaromatic hydrocarbons such as benzene).

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	Sampling Site							
	South Portage Bay	Portage Bay near Yacht Club	University Regulator CSO	Portage Bay off park	North Lake Union	Lake Union near Steam Plant	Mid Lake Union	Ship Canal at Fremont Bridge
Total Abundance (animals/m^2)	46,884	7,410	12,613	6,364	3,827	5,805	588	1,319
Species Richness (number of taxonomic groups)	17.33	22.33	14.67	17.67	15.33	9.67	3.67	7.33

Ten most abundant taxonomic groups (all sites combined):

Rank	Taxonomic groups	Other Names
1.	Nematoda	Nematode, roundworm
2.	Ostracoda	Water "flea"
3.	Oligochaetes (immature with bifids)	Aquatic earthworm
4.	Pisidium	Freshwater clam, pelecypod
5.	Chironomus	Two-winged fly, chironomid
6.	Procladius	Two-winged fly, chironomid
7.	Asellus racovitzai	Isopod
8.	Hyatella azteca	Amphipod, shrimp
9.	Oligochaetes (immature with hairs and pectinates)	Aquatic earthworm
10.	Limnofrilus hoffmeisteri	Aquatic earthworm, tubificid

[1]Benthic infauna values represent means of three replicates. Samples were sieved through a 0.25mm sieve.

Source: Anderson, et al. 1987.

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GLOSSARY

Algae -- Aquatic, nonflowering plants that lack roots and use light energy to convert inorganic nutrients such as nitrogen and phosphorus into organic matter by photosynthesis. Algal bloom can occur when excessive nutrient levels and other water conditions enable the algae to reproduce rapidly.

Amphipod Mortality Test -- A bioassay procedure in which amphipods (a large group of crustaceans composed of sand fleas and other related forms of animals) are exposed to various concentrations of sediments and percent mortality is measured.

Apparent Effects Threshold -- The concentration of a toxicant above which statistically significant biological effects are observed, based on synoptic field data.

Benthic Infauna -- The benthic invertebrates that live beneath the sediments.

Bioassay -- A laboratory test using a response of a test plant or animal (e.g., its growth or death) to measure the effect of a physical, chemical or biological variable.

Biota -- The animal and plant life of a particula region.

Chemical Oxygen Demand (COD) -- The quantity of oxygen-demanding chemical materials present in a sample as measured by a specific test. COD is defined as a conventional pollutant under the Federal Clean Water Act.

Coliform Bacteria -- A type of bacteria which includes many species. Fecal coliform bacteria are those coliform bacteria which are found in the intestinal tracts of warm-blooded animals. The presence of high numbers of fecal coliform bacteria in a water body can indicate the release of untreated sewage, and/or the presence of animals, and may indicate the presence of pathogens.

Combined Sewer Overflow (CSO) -- A pipe that discharges untreated wastewater during storms, from a sewer system that carries both sewage and stormwater. The overflow occurs because the system does not have the capacity to transport and treat the increased flow caused by stormwater runoff.

Conductivity -- The property of conducting (transmitting) electricity. In the case of Lake Union, there is a positive correlation between conductivity and salinity of the Lake bottom. Hence, high conductivity reflects high saltwater intrusion into the Lake.

Conventional Pollutant -- One of the pollutants specified under the Federal Clean Water Act. The list includes total suspended solids, coliform bacteria, BOD, COD, pH, and oil and grease.

Dissolved Oxygen (DO) -- Oxygen which is present (dissolved) in water and therefore available for fish and other aquatic animals to use. If the amount of dissolved oxygen in the water is too low or zero, then exposed aquatic animals will die.

Gram -- A unit of weight in the metric system, 454 grams = 1 pound and 28.4 grams = 1 ounce.

Groundwater -- Underground water supplies, created by rain which soaks into the ground and flows down until it is collected at a point where the ground is not permeable. Groundwater then usually flows laterally toward a lake, river or the ocean.

Interstitial Water -- Water that is found in between sediment particles.

Mesotrophic -- Moderately transparent, with moderate levels of algae and algal nutrients. This term is used in reference to lakes.

Microgram -- One-one millionth (1/1,000,000) of a gram.

Milligram -- One-one thousandth (1/1,000) of a gram.

Organic Chemical -- A chemical that contains carbon.

Polychlorinated Biphenyls (PCBs) -- A group of ubiquitous, environmentally persistent chlorinated hydrocarbons (between 12% - 68% chlorine). PCBs were formerly used in insulating fluids in capacitors and transformers, in the plastics industry, and in hydraulic fluids and lubricants. PCBs can cause cancer. They have caused birth defects in laboratory animals and are believed to be capable of causing birth defects in humans also.

Polycyclic Aromatic Hydrocarbons (PAHs) (sometimes called polynuclear aromatics or PNAs) -- Many-ringed organic chemicals containing carbon and hydrogen. They are formed as a result of incomplete combustion of organic materials, e.g., coal, coke, wood, tobacco. Some PAHs can cause cancer.

ppm -- Parts per million; 1 ppm of a chemical means 1 gram of that chemical in every 1,000,000 grams (1,000 liters) of water.

ppt -- Parts per thousand; 1 ppt salinity means 1 gram salt in every 1,000 grams (1 liter) of water. The concentration of dissolved salt in seawater is 35 ppt.

Priority Water Pollutants -- 126 toxic water pollutants so designated by EPA under the Federal Clean Water Act because they have several of the following properties: 1) demonstrated ability to kill aquatic organisms; 2) cause cancer; 3) ability to bioconcentrate; 4) environmentally persistent; 5) ubiquitous; 6) volume of production or use by industry; 7) capability of analytical detection. The list includes metals, asbestos, cyanide, and organic (carbon-based) chemicals such as PCBs, PAHs, and pesticides.

Reference Site -- A "control site" in an environmental study. The reference site (e.g., a pristine lake) has similar characteristics to the test site but has not been subjected to human activities that cause water pollution.

Sediment -- Material suspended in or settling to the bottom of a liquid. As used here, it refers to the sand and mud that makes up much of the shorelines and bottom of Lake Union/Ship Canal.

Species Diversity -- A measure of the number and types of species found in a particular community of plants and animals, e.g., a benthic community. Species diversity can be an indicator of pollution. Benthic communities in highly polluted sediments may show less species diversity than benthic communities in nonpolluted sediments.

Storm Drain -- A system of gutters, pipes, or ditches used to carry stormwater from surrounding lands to streams, lakes, or Puget Sound. Often carries a variety of substances such as oil and antifreeze which enter the system through runoff, deliberate dumping, or spills. This term also refers to the end of the pipe where the stormwater is discharged.

Stormwater -- Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.

Synoptic -- Presenting or involving data from the same point of view. In this study it refers to chemical and biological data from the same sediment sample.

Taxonomic Group -- A group of plants or animals with common structural features and biological characteristics.

Toxicant -- A chemical that poses a risk of producing an adverse biological effect or in some way damaging a living organism.

Turbidity -- A measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. High levels of turbidity are harmful to aquatic life.

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